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ABSTRACT

This instructor's guide is designed for use with the Unified Technical Concepts (UTC) system for teaching applied physics in two-year postsecondary institutions. Following an introductory section, the first of three additional sections gives the background of the UTC approach to physics instruction. The second section describes the structure of the 13 concept modules, 170 application modules, and 8 supplementary modules. The final section is comprised of implementation guidelines in the areas of course construction, presentation of UTC, and ordering modules. Appended material includes a module selection matrix, concept module summary charts, module summaries, and solutions to module self-check problems. (LRA)

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UNIFIED TECHNICAL CONCEPTS

INSTRUCTOR'S GUIDE

DEVELOPED BY

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PREFACE

Complex, modern equipment often contains combinations of hydraulic, thermodynamic, pneumatic, or optical subsystems, as well as mechanical and electrical components. The subsystems and components appear, not in isolation, but as interdependent parts of such complex systems. Consequently, a modern technician must understand not only the separate subsystems, but also their interrelationships and the role they play in an integrated system.

Educational programs for preparing technicians should provide a broad, interdisciplinary technical base. This base should logically be developed when the students are introduced to the principles and concepts that form the foundation of the particular technical specialty — i.e., in the technical physics courses.

Educational and technical experts have collaborated for over three years to devise, develop and test a unique teaching strategy for technical physics. Grants were provided by the U. S. Office of Education's Bureau of Adult and Occupational Education for the development of suitable educational materials.* The Unified Technical Concepts (UTC) approach to physics was conceived with a goal of developing modules that relate directly to applied physics, to industry, and to the technologies. This approach emphasized both the analogies between basic physical principles and the applications of these principles in modern technology.

UTC is an alternate method of presenting what has been a formidable, and sometimes confusing, subject for technicians. It provides laboratory experiments that apply to specific technological fields, allowing students to relate more quickly to module content: they understand how it affects them in their technology.

UTC represents a unique approach to the teaching of applied physics. Its flexible modular format allows it to be tailored by physics and technology instructors to meet specific needs of students in each technology.

Experimental field use of UTC began in September, 1977, at two technical schools and at one community college. A significant finding was that student comprehension and success of the UTC approach were directly influenced by the enthusiasm, complete understanding, and continued emphasis of analogies by the instructor. Because the instructor is the key to success or failure, this document is designed to provide support information useful to anyone planning to teach UTC. Although the reading and implementing of the suggestions provided will not guarantee success, the instructor will encounter fewer obstacles by following an approach similar to the one presented in this Instruction Guide.

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*"Modularizing Instructional Materials Using Application of Technical Concepts." Technical Education Research Center — Southwest; Grant G007701952 and Grant G007603926, Department of HEW, Office of Education, Bureau of Adult and Occupational Education, Washington, D.C.

ACKNOWLEDGMENTS

This project was conceived out of needs expressed by many faculty members and administrators of two-year, postsecondary institutions and the industrial experience of the project director; however, ideas for a unified approach to physics were presented as early as the turn of the century and specified in 1972 in a curriculum development project for Electromechanical Technology* directed by Dr. Maurice W. Roney.

Encouragement to undertake the task of "restructuring physics" was provided by Dr. Walter J. Brooking, Technical Consultant, U. S. Office of Education. The project tasks have been conducted by the TERC-SW staff (Johnny Jones, Ellis Lindsey, Vernon Woolf, Carl Lansford and Bruce Lube) and assisted by Chief Technical Consultant and Editor, Dr. Leno S. Pedrotti U. S. Air Force Institute of Technology. Experimental use of instructional materials has been conducted at three innovative schools: Texas State Technical Institute, Harlingen, Texas; North Central Technical Institute, Wausau, Wisconsin; and Camden County College, Blackwood, New Jersey.

Sponsorship of this project was provided by a grant from the Research Division, U. S. Office of Education, Bureau of Adult and Occupational Education, Dr. Glenn Boerrigter, Branch Chief.

Daniel M. Hull
Project Director

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UNIFIED TECHNICAL CONCEPTS
INSTRUCTOR'S GUIDE

UTC

Unified Technical Concepts (UTC) is a unique way of presenting relevant physics for a variety of technologies. In its broad selection of modules, UTC relies heavily upon the natural unity in physics, seen in twelve basic concepts, including force, resistance, and power. The Concept Modules include, where applicable, practical applications in four principal energy areas (mechanical. fluidal, electrical, and thermal).

MODULE

The term "module" in an educational sense implies a self-contained unit of instruction; therefore, educational modules can be described as components of either a course or a curriculum. Each UTC module contains a student text, a hands-on laboratory exercise, and a set of specific performance objectives, around which the module is constructed and by which student mastery can be measured. Each module consists of from one to four hours of instruction and can be combined with others to construct a course or curriculum of chosen breadth.

INTRODUCTION

Specialization in technical education always has been a major attraction for students. In many cases, it is a key motivator: students come to technical schools to study real-world applications, not abstract theories and principles. Subjects such as mathematics and physical sciences, if presented in traditional forms, do little to motivate technical students. Unless technical students can apply personally and actively these concepts to something they consider interesting and appropriate, optimum learning is not likely to occur.

Unified Technical Concepts (UTC) is a new and innovative way of presenting relevant physics specific to a variety of technologies. Its com-

ponent parts are flexible, allowing technical faculty to choose from a "shopping list" of physics topics those subjects that relate directly to a student's chosen technical specialty.

UTC provides the specialization and, at the same time, develops a broad, diversified system of orientation for technicians. It teaches physical concepts such as force, resistance, and power and relates them to the technology through practical applications in the four principal energy forms (mechanical, fluidal, electrical, and thermal). This modularized approach relies heavily upon analogies and applied relationships of basic concepts by putting traditional physics and engineering into "work clothes."

The increasing complexity of modern industry and the scope of emerging energy-related technologies is causing a rapid change in occupational skill requirements. A new generation of "systems" technicians having broad, interdisciplinary training is needed. Employers are searching for such technicians and are retraining existing employees to perform technically-diversified work. In addition, emerging technologies require upgrading in the form of cross-training in different technical areas of physics in order to respond rapidly to new technological opportunities. Both situations demand a more flexible method of physics instruction.

To fulfill industry's need for qualified technicians, schools are attempting new curricula, flexible strategies, and varied teaching techniques. They are attempting to make both their pre-employment programs and their adult education more relevant to such work requirements.

Furthermore, as more students enter technical/vocational education, pressure becomes greater for schools to make more efficient use of their existing facilities and staff. Also, to meet changing requirements, technical/vocational education programs need to be flexible enough for students' narrow, short-term occupational goals, yet deep and broad enough to prepare them for vertical and horizontal occupational mobility. UTC is ideally suited to accomplish these goals of responsiveness, relevancy, and effectiveness.

Because UTC is unique in its approach, instructors will find it necessary to orient themselves to its innovative philosophy, as well as to its processes of design and implementation. This document provides the

necessary background, and a review of it should produce a more informed, more confident, and better-prepared instructor.

BACKGROUND

Physics traditionally is divided into several branches such as mechanics, heat, light, sound, electricity, magnetism, atomic physics, etc. Each of these branches usually is treated as a separate course or section within a course. Students usually begin by studying mechanics. Once the basics of this branch of physics are mastered, they move on to other branches, studying one at a time. Little, if any, attempt is made to have the students examine similarities between these branches of physics.

This traditional approach to teaching physics is unsuitable for use in technical programs for the following reasons:

- Students often fail to see how the physics they study relates to their chosen technologies; this lack of understanding reduces motivation and comprehension.
- A great amount of instructional time often is required to teach the principles of physics when only one branch (usually mechanics) is used as an example. This approach leaves insufficient time for adequate coverage of other areas that actually may be more important to job performance.
- Because little effort is made to draw the students' attention to the similarities of various branches of physics, they often are unable to apply the knowledge they have gained to unfamiliar problems, particularly to those that involve more than one branch of physics.

UTC was developed to provide for technical programs a system of physics instruction that will maximize the effectiveness of instructional time and will provide the student with a knowledge of basic physics that is well-ordered, practical, and easy to apply to realistic technical problems.

UTC was developed over a period of three years and was based upon ideas from a national committee, consisting of representatives from indus-

try, research, and technical education. It has undergone extensive field testing and revision. Every effort has been made to incorporate the elements of traditional physics that have proved successful in technician training and to merge these with new approaches tested in the classroom and laboratory. The result is a restructuring of physics that includes the following instructional strategies:

- UTC is structured around "concepts" common to several branches of physics. Concepts are taught with the aid of examples and applications from each branch of physics to which they apply. The concept of resistance, for example, applies to mechanical friction, fluid resistance in pipes, electrical resistance in wires, and thermal resistance of insulation. The concepts presented in UTC include both "pure physics" such as force, rate, resistance, and power and technically-important areas of "applied physics" such as energy convertors and transducers.
- Because of the ever-increasing awareness of energy and the natural divisions forming the branches of physics, energy has been chosen as a central theme. UTC investigates each physics concept as it applies to four "energy systems" — Mechanical, Fluidal, Electrical, and Thermal.
- A wide variety of laboratory equipment is used in UTC. Standard physics laboratory equipment such as force tables and Boyle's Law apparatus are used when they are the most appropriate means of demonstrating principles, but most laboratories use "real-world" equipment such as electric motors, shock absorbers, and residential insulating materials. Low-cost alternatives often are included for economy. Each laboratory exercise in UTC is designed to demonstrate clearly the application of a single concept in a single energy system.
- The mathematics employed in UTC has been limited to the minimum level acceptable to describe the physics involved; therefore, one year of high school algebra is adequate preparation. Supplementary materials are provided for students who require additional math skills or review.
- Units are introduced and defined in each energy system, along

with the concept to which they apply. Both English and SI units are used.

- UTC modules have been written to afford maximum flexibility in course design. By prudent selection, courses can be designed to satisfy the needs of students in a wide variety of technologies. Students with dissimilar interests can be accomodated in a single class in which they study the same concepts in the lecture but concentrate on different applications in the laboratory.

The combination of all these factors allows the instructor to teach more useful physics in less time and aids students in relating that physics to their individual technologies.

STRUCTURE OF UTC

UTC consists of three types of modules — Concept, Application, and Supplementary. Each of these is described below. (Refer to Table 1 and to Appendix A, "Module Selection Matrix," for a complete list of titles.)

CONCEPT MODULES

Thirteen Concept Modules form the backbone of UTC. Each of these modules presents a single concept and discusses the application of that concept in each energy system.

1-0 FORCE

This module describes forcelike quantities as "the physical quantities that produce motion." The following forcelike quantities are discussed:

Mechanical — force and torque.
Fluidal — pressure difference.
Electrical — potential difference.
Thermal — temperature difference.

2-0 WORK

"Work" is defined as "the product of a forcelike quantity and

a displacementlike quantity" in each energy system.

3-0 RATE

"Rate" refers to "the quotient of a displacementlike quantity and elapsed time" in each energy system.

4-0 MOMENTUM

"Momentum" is defined as "the product of mass and velocity" in mechanical and fluidal systems. Electrical and thermal systems are not discussed as momentum analogies because these systems are beyond the scope of UTC.

5-0 RESISTANCE

Static and sliding friction are investigated as examples of resistance in mechanical systems. For other energy systems, resistance is defined as "the ratio of forcelike quantity to rate."

6-0 POWER

"Power" is "the rate of doing work" in each energy system. The efficiency of devices that convert power from one form (energy system) to another is defined and discussed.

7-0 POTENTIAL AND KINETIC ENERGY

Concept Module 7-0 describes potential and kinetic energy in each energy system, the conservation of energy, and Bernoulli's Equation in fluidal systems.

8-0 FORCE TRANSFORMERS

"Force transformers" are defined as "devices that transform an input forcelike quantity and displacement into a different output forcelike quantity and displacement in the same energy system (levers, hydraulic jack, electrical transformers)." Thermal systems are not discussed, as there are no transformers of temperature difference.

9-0 ENERGY CONVERTORS

The operation and efficiency of devices that transform energy from one energy system to another are described in this module. A wide variety of energy convertors are discussed. Optical

TABLE 1

SUPPORT MODULES	S1 Formula Interpretation S2 International System of Units S3 Logarithms and Exponents S4 Angles and Triangles		S5 Vectors and Scalars S6 Dimensional Analysis S7 Reading and Drawing Graphs S8 Precision, Accuracy and Measurement	
CONCEPTS	**ENERGY SYSTEM**			
	MECHANICAL	**FLUIDAL**	**ELECTRICAL**	**THERMAL**
	1-0 CONCEPT MODULE: QUANTITIES THAT CAUSE MOVEMENT			
1-0 FORCE	1M1 Gravity 1M2 Addition of Mechanical Forces 1M3 Addition of Torques 1M4 Mechanical Equilibrium in Structures 1M5 Stress and Strain 1M6 Tension in Wires and Cables	1F1 Atmospheric Pressure 1F2 Density, Buoyancy, and Specific Gravity 1F3 Hydraulic Jack 1F4 Manometers	1E1 Potential Difference and Charge Flow 1E2 Series and Parallel Voltage Sources 1E3 Electric Forces and Fields 1E4 Magnetic Forces and Fields 1E5 Lead-Acid Storage Battery	1T1 Thermometers 1T2 Temperature Difference and Heat Flow 1T3 Thermal Stress
	2-0 CONCEPT MODULE: WORK = FORCELIKE QUANTITY X DISPLACEMENT			
2-0 WORK	2M1 Work Done on an Elevator 2M2 Work Done by a Winch	2F1 Work Done by a Water Pump 2F2 Work Done by a Hydraulic Lift		2T1 Heat Energy Required for a Temperature Increase 2T2 Heat Energy Required for Melting 2T3 Heat Energy Required for Boiling 2T4 Fundamentals of Air Conditioning
	3-0 CONCEPT MODULE: RATE = DISPLACEMENT / TIME ELAPSED			
3-0 RATE	3M1 Graphic Approach to Linear Motion 3M2 Velocity at Constant Acceleration 3M3 Displacement at Constant Acceleration 3M4 Acceleration of a Mass by Constant Force 3M5 Rotational Motion 3M6 Radial Acceleration and Centripetal Force	3F1 Flow Rate Measurement with a Venturi Meter	3E1 Electric Current 3E2 Frequency	3T1 Heating and Cooling Rate 3T2 Rate of Heat Conduction
	4-0 CONCEPT MODULE: FORCELIKE QUANTITY X TIME APPLIED = INERTIAL QUANTITY X RATE			
4-0 MOMENTUM	4M1 Angular Momentum of a Flywheel 4M2 Impulse and Momentum 4M3 Conservation of Momentum in Collisions 4M4 Gyroscopes	4F1 Rocket Engines		
	5-0 CONCEPT MODULE: RESISTANCE = FORCELIKE QUANTITY X RATE			
5-0 RESISTANCE	5M1 Static and Sliding Friction 5M2 Effect of Lubricants 5M3 Rolling Friction	5F1 Laminar and Turbulent Flow 5F2 Viscosity 5F3 Fluid Resistance in Pipes 5F4 Valves and Regulators 5F5 Shock Absorbers 5F6 Drag-Resistance to Motion Through Fluids	5E1 Ohm's Law 5E2 Series and Parallel Resistors 5E3 Internal Resistance of a Battery 5E4 Conductors, Semiconductors, and Insulators 5E5 Resistance of Wires 5E6 Resistance of Semiconductor Junctions 5E7 Resistance of Gas Laser Tubes 5E8 Volt-Ohm-Milliammeter	5T1 Thermal Conductivity 5T2 Heat Flow Through Insulation

6-0 POWER	**6-0 CONCEPT MODULE: POWER = WORK / TIME ELAPSED**			
	6M1 Horsepower 6M2 Prony Brake	6F1 Hydraulic Power	6E1 Electrical Power Measurement 6E2 Electric Heater 6E3 Efficiency of Electric Motors and Generators 6E4 Electrical Power Consumption	6T1 Heat Exchangers
7-0 POTENTIAL AND KINETIC ENERGY	**7-0 CONCEPT MODULE: CONSERVATION OF ENERGY**			
	7M1 Piledriver 7M2 Potential Energy of a Spring 7M3 Rotational Kinetic Energy of a Flywheel 7M4 Conservation of Energy in Collisions 7M5 Kinetic Energy and Horsepower of an Automobile	7F1 Energy Stored in Large Tanks 7F2 Venturi Meters 7F3 Pitot Tubes 7F4 Energy Conversion in Fluid Systems 7F5 Gas Laws 7F6 Siphons	7E1 Energy Stored in a Battery 7E2 Energy Stored in a Capacitor 7E3 Energy Stored in an Inductor 7E4 Series and Parallel Capacitors	7T1 Heat Storage Systems 7T2 Electrical Equivalent of Heat 7T3 Mechanical Equivalent of Heat 7T4 Thermal Drying 7T5 Mixing Liquids at Different Temperatures
8-0 FORCE TRANSFORMERS	**8-0 CONCEPT MODULE: PRINCIPLES OF SIMPLE MACHINES**			
	8M1 Levers 8M2 Wedges and Inclined Planes 8M3 Drive Systems 8M4 Gear Trains 8M5 Block and Tackle 8M6 Differential Hoist	8F1 Hydraulic Press	8E1 Electrical Transformers	
9-0 ENERGY CONVERTORS	**9-0 CONCEPT MODULE: DEVICES TO CONVERT ENERGY FROM SYSTEM TO SYSTEM**			
		9F1 Turbines 9F2 Fluid Pumps 9F3 Wind Power 9F4 Fans and Blowers 9F5 Vacuum Pumps	9E1 Electric Generators 9E2 Alternators 9E3 Electric Motors 9E4 Solenoids and Relays 9E5 Photovoltaic Materials	9T1 Boilers 9T2 Thermoelectric Generators 9T3 Solar Collectors
10-0 TRANSDUCERS	**10-0 CONCEPT MODULE: DEVICES TO TRANSFORM INFORMATION FROM ONE SYSTEM TO ANOTHER**			
	10M1 Strain Gages 10M2 Accelerometers	10F1 Bourdon Tubes 10F2 Aneroid Barometers 10F3 Differential Pressure Transducers 10F4 Fluid-Flow Measuring Devices 10F5 Vacuum Gages	10E1 Meter Movements	10T1 Automobile Thermostats 10T2 Bimetallic Strips 10T3 Temperature Measuring Devices 10T4 Thermocouples 10T5 Thermistors 10T6 Pyrometers
11-0 VIBRATIONS AND WAVES	**11-0 CONCEPT MODULE: MECHANICAL ENERGY TRANSFER THROUGH PERIODIC MOTION**			
	11M1 Speed of Sound in Materials 11M2 Reflection and Absorption of Sound Energy 11M3 Vibration Isolation 11M4 Resonance 11M5 Sound Speakers	11F1 Cavity Vibrations and Standing Waves 11F2 Speaker Enclosures 11F3 Reverberation Time 11F4 Doppler Effect 11F5 Pressure Measurement of Sound Waves	11E1 Alternating Voltage and Current 11E2 Phase Relationships in a.c. Circuits 11E3 Oscilloscope 11E4 Rectifiers 11E5 Electronic Filtering in d.c. Power Supplies 11E6 Electronic Filtering for Frequency Selection 11E7 Modulation of Electrical Waves	
12-0 TIME CONSTANTS	**12-0 CONCEPT MODULE: QUANTITIES VARYING EXPONENTIALLY WITH TIME**			
	12M1 Shock Isolation by Absorbers	12F1 Rate of Emptying Tanks	12E1 RC Circuits 12E2 RL Circuits 12E3 RLC Circuits	12T1 Response Time of Thermocouples 12T2 Time Constants of Heating and Cooling
13-0 RADIATION	**13-0 CONCEPT MODULE: ELECTROMAGNETIC AND PARTICLE RADIATION**			
	13L1 Inverse Square Law — Spreading of Light 13L2 The Optical Spectrum 13L3 Light Sources 13L4 Lasers 13L5 Stroboscopes — Light Pulses 13L6 Optical Filters — Absorption of Light 13L7 Specular and Diffuse Reflection of Light	13L8 Image Formation with Mirrors 13L9 Prisms — Refraction and Dispersion of Light 13L10 Lenses — Focusing and Spreading of Light 13L11 Interference — Testing Flat Surfaces 13L12 Diffraction Grating — Measuring the Wavelengths of Light	13L13 Polarization — Glare Reduction 13L14 Holography — Three Dimensional Photography 13L15 Spectroscopy — Light Analysis 13L16 Infrared Radiation Thermometers 13L17 Illumination 13L18 Single Lens Reflex Camera	13N1 Geiger Counters 13N2 Penetrating Power of Alpha and Beta Radiation 13N3 Radioactivity 13N4 Absorption of Gamma Radiation

(light) energy is included in this concept as a fifth energy system.

10-0 TRANSDUCERS

Here, "transducers" are defined as "devices that change information-carrying signals in one energy system to signals in mechanical, electrical, or fluidal systems." The operations of several important transducers in each energy system are discussed as examples.

11-0 VIBRATIONS AND WAVES

The basics of wave behavior with examples in mechanical, fluidal, and electrical systems are explained. The discussion includes the wave equation, superposition, and interference of waves.

12-0 TIME CONSTANTS

In this module, an explanation is given of time constants used to describe exponential increase and decrease functions in all energy systems. Radioactive decay is included as an additional example.

13-0 RADIATION

Both electromagnetic and particle radiation are explored in this module, which is organized under these two topics rather than under the usual energy systems. Properties of electromagnetic radiation discussed include the inverse square law, polarization, reflection, and refraction.

STRUCTURE OF CONCEPT MODULES

Each UTC Concept Module contains the following elements:

INTRODUCTION

Each Concept Module is introduced by a brief description of the concept to be discussed and includes examples of its application in the energy system to which it applies.

PREREQUISITES

A list of prerequisite UTC modules and any special knowledge or

skills required for successful completion of the module is provided following the Introduction.

OBJECTIVES

A number of specific tasks that students should be able to accomplish after the completion of the module are stated in behavioral terms. Some objectives are concerned with the unification of the concept in several energy systems; others apply to specific applications of the concept in a single energy system.

DISCUSSION

The Discussion is the "text" of the module and begins with the definition of the concept as it applies in all energy systems to be considered. Applications of the concept are discussed in each energy system, together with the use of appropriate equations, figures, tables, example problems, and practical technical applications. All appropriate units are defined for each energy system. The order of energy systems in most Concept Modules is (1) mechanical, (2) fluidal, (3) electrical, and (4) thermal.

SUMMARY

Immediately following the Discussion in each Concept Module is a Summary, which stresses unification by explaining the similarity of the concept as it applies in different energy systems.

DEMONSTRATIONS

The Demonstrations section contains the materials and procedures necessary for performing classroom Demonstrations that illustrate the applications of the concept in each energy system. Spaces are provided for students to record data and results when appropriate. Some Demonstrations are simple and quickly performed, although others are more complicated and can be used as student exercises.

SELF CHECK

The Self Check consists of a set of problems and questions based upon the module Objectives and intended for use by students to check their own understanding of the module content. Appendix D provides the instructor with valuable and time-saving "Solutions to Self Check Problems" that require calculations.

REFERENCES

The References are bibliographical sources that direct students to additional information on topics discussed in the module.

APPLICATION MODULES

Each of the 170 Application Modules discusses the application of a single concept in a single energy system. The elements of an Application Module are the same as those of a Concept Module. The following comments apply to the sections of UTC Application Modules:

- The INTRODUCTION identifies the concept and explains how it applies to the particular application to be discussed.
- PREREQUISITES always include the Concept Module under which the Application Module is listed.
- OBJECTIVES include the completion of one or more laboratory exercises by the students.
- The DISCUSSION includes both practical examples and the development of the theory upon which the laboratory is based.
- The SUMMARY is an overview of the module and includes a reference to the concept being demonstrated.
- The LABORATORY replaces "Demonstrations" and consists of one or more hands-on experiments.
- The SELF CHECK provides problems and questions concerning the application of the concept.
- REFERENCES indicate sources of additional information concerning the application of the concept and of the devices discussed in the module.

Application Modules are identified by a number that indicates both their concept and energy system. 5M3, "Rolling Friction," for example, is the third (3) mechanical (M) Application Module listed under Concept 5-0, "Resistance." This system indicates that Concept Module 5-0 is prerequisite to 5M3, but that 5M1 and 5M2 are not necessarily prerequisites. Figure 1 clarifies both this numbering system and the basic structure of UTC.

CONCEPT MODULE	CONCEPT 1-0 FORCE			
	Force and Torque	Pressure Difference	Potential Difference	Temperature Difference
ENERGY SYSTEMS	MECHANICAL	FLUIDAL	ELECTRICAL	THERMAL
APPLICATION MODULES	1M1 Gravity 1M2 Addition of Mechanical Forces 1M3 Addition of Torques 1M4 Mechanical Equilibrium in Structures 1M5 Stress and Strain	1F1 Atmospheric Pressure 1F2 Density, Bunyancy and Specific Gravity 1F3 Hydraulic Jack 1F4 Manometers	1E1 Potential Difference and Charge Flow 1E2 Series and Parallel Voltage Sources 1E3 Electric Forces and Fields 1E4 Magnetic Forces and Fields 1E5 Lead-Acid Storage Battery	1T1 Thermometers 1T2 Temperature Difference and Heat Flow 1T3 Thermal Stress

FIGURE 1.

UTC Application Modules may be categorized in several ways. One of the following descriptive phrases applies to the topics presented in each Application Module (an example of each type is included):

- An expansion of the physics discussed in the Concept Module, usually including a more detailed mathematical description (1M3, "Addition of Torques").
- The introduction of new physics based upon the concept but not discussed in the Concept Module (1E3, "Electric Forces and Fields").
- The investigation of a phenomenon based upon the concept (5E5, "Resistance of Wires").
- The description and operation of a device based on the concept (5F5, "Shock Absorbers").

- A description of the application of the concept within a subsystem of some larger system (6F1, "Hydraulic Power").

Those Application Modules containing "new" physics or a more detailed mathematical development are identified in Appendix A, "Module Selection Matrix," and Appendix C, "Module Summaries," by an asterisk following the module number.

SUPPLEMENTARY MODULES

The following eight Supplementary Modules provide necessary background material in their respective areas and explain its application in UTC:

S1 Formula Interpretation.
S2 International System of Units.
S3 Logarithms and Exponents.
S4 Angles and Triangles.
S5 Vectors and Scalars.
S6 Dimensional Analysis.
S7 Reading and Drawing Graphs.
S8 Precision, Accuracy, and Measurement.

The structure of Supplementary Modules is the same as that of UTC Application Modules. The laboratory exercises require the use of pencil, paper, calculator, and measuring and graphing tools.

IMPLEMENTATION

The first step in implementing UTC is to identify the technologies to be served. When the technologies have been determined, the physics instructor is encouraged to consult with instructors of the technologies to select appropriate modules for their students. Since the technology instructors probably lack familiarity with UTC, the physics instructor should be prepared to recommend specific modules to meet the needs expressed by technology instructors. By using Appendix A, "Module Selection Matrix," and Appendix C, "Module Summaries," as selection tools, a course tailored for each technology can be agreed upon and constructed.

COURSE CONSTRUCTION

Experimental field use of UTC in several schools indicates that the time requirements for UTC modules vary according to the technology served, student background, and instructor preference. A general guideline is to allow six hours of lecture per Concept Module and one and one-half hours of laboratory per Application Module, but each instructor is strongly advised to review proposed modules and make his or her own estimates based upon the particular class involved. Note: Although the average time for a laboratory is an hour and a half, some laboratories can be completed by better students in thirty minutes; and a few require several hours.

Concept selection and order can be accomplished with the aid of Figure 2. The following suggestions should be considered carefully:

CONCEPT FLOW CHART

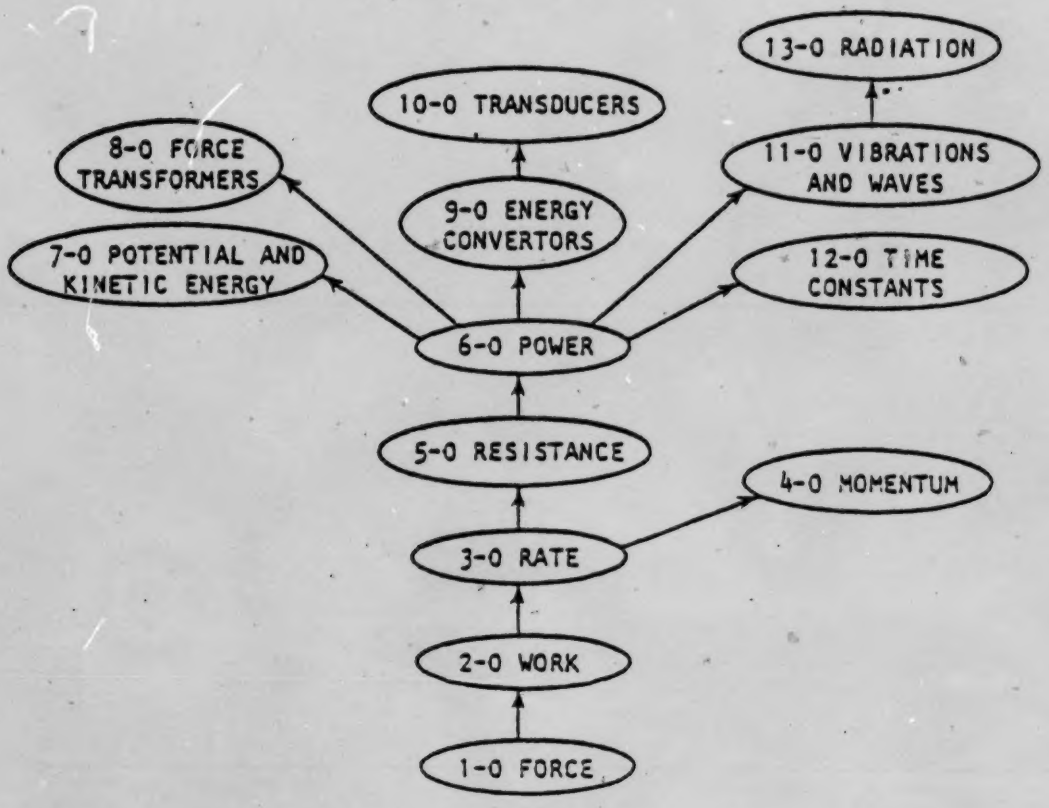


FIGURE 2

- Concepts 1-0, 2-0, 3-0, 5-0, and 6-0 form a linear sequence, and should be presented in that order. All students taking UTC should study these five concepts as a minimum.
- Concept 4-0, "Momentum," can be studied anytime after 3-0, "Rate," but often is deleted in favor of concepts of greater relevance.
- After Concept 6-0, "Power," any order may be chosen, provided that 9-0 precedes 10-0 and that 11-0 precedes 13-0. This flexibility allows later concepts to be ordered in such a manner as to meet prerequisites for courses taken concurrently with UTC.

Once the Concept Modules have been selected, appropriate Application Modules are chosen. Module prerequisites should be checked carefully, as some Application Modules have as prerequisites Application Modules from earlier concepts. The following two notes are important in the selection and ordering of Application Modules:

- Application Modules 1E3, "Electric Forces and Fields," and 1E4, "Magnetic Forces and Fields," are prerequisite to many Application Modules and to Concept Module 13-0, "Radiation."
- Some Application Modules that describe measuring equipment may be presented effectively before their concepts in order to familiarize students with equipment. These modules include 5E8, "Volt-Ohm-Milliammeter," and 11E3, "Oscilloscope."

Supplementary Modules may be presented at any time, but are most effective if studied concurrently with related material in Concept and Application Modules.

PRESENTATION OF UTC

UTC is an extremely versatile package and may be taught in a variety of ways. The following points should be considered in the planning of teaching strategies for UTC:

- Concept Modules are designed for lecture presentation. The appropriate sections of each Concept Module should be discussed in class before students perform laboratory exercises based upon that concept.

- Some Application Modules should be discussed in class before students attempt the laboratory; others can be presented easily as self-paced laboratory exercises. Instructors are encouraged to review all materials and to determine the best approach for each class.
- Students from different technologies may study different applications of the same concept during one laboratory period. This enhances learning by allowing students to observe experiments that they themselves do not perform.
- Several different Application-Module experiments can be set up within a single lab in which students perform experiments in rotation. This method allows fewer lab stations for each module.
- Most experiments in UTC can be set up by the students, but a few require more complicated setups that must be provided.
- Students should be encouraged to answer all Self-Check questions and to work all problems.
- Testing should be based upon module objectives. Instructors adding or deleting material are encouraged to inform students of the addition or deletion of objectives.
- UTC modules contain space for the recording of experimental data, but no specific instructions on laboratory reports are given. Such instructions are left to the discretion of the instructor.
- The instructor is urged to point out analogies between various energy systems at every opportunity. Unification should be stressed particularly at the beginning and end of the presentation of each Concept Module. Appendix B, "Concept Module Summary Charts," contains a summary chart of each Concept Module to be used for this purpose.

ORDERING MODULES

UTC modules are available packaged in three-ring notebooks that contain approximately 35 modules each. The following procedure is suggested when ordering UTC modules:

- Enter the technology to be served in the space indicated at the top of the "UTC Module Selection Matrix."
- Enter the number of sets of modules required
- Place an "X" in the box to indicate each module ordered in the set.
- Use additional columns for additional technologies.

The selected modules will be packaged into sets and identified by technology.

Modules also may be purchased on an individual basis.

CONCLUSIONS

Use of the UTC approach can accomplish the following:

- A course can be constructed to emphasize the specific need(s) of each student or class, resulting in a tailormade curriculum.
- The flexible (modular) format allows easy scheduling and addition or deletion of instructional material as technology needs change.
- Physical concepts and their applications are made understandable to students, removing the "theory-without-knowledge-of-application" mystery and the drudgery from physics studies.
- Common apprehension about physics and physics equipment is reduced by employing the same kinds of equipment and materials used in technology.
- Motivation of a technician's interest in physical principles is maximized by placing in easily-understood perspective the application and analogous relationship of each concept to a technology.
- By using UTC, the technical student's understanding of relationships is increased, making the technician more valuable to a potential employer. As an employee, this background will allow an individual greater mobility, both horizontally and vertically, in a field.

The reward of success to the instructor can be ensured by instructional preparation in the following ways:

- Gaining a thorough understanding of the philosophy and mechanics of UTC.
- Accepting the precept that UTC offers a beneficial approach to a complex subject.
- Emphasizing to students, at every opportunity, the analogies stressed in the UTC approach.
- Using time created by students working on self-paced Application Modules to interact with other students on a one-to-one basis.
- Taking the initiative (and time) to gather equipment needed for laboratory experiments.
- Being willing to tolerate inconveniences and flexibility caused by initiating a radically-new teaching program.

Instructors who have used UTC indicate that students experienced initial difficulty in understanding the approach, but that once they had grasped the structure of UTC, their motivation and rate of learning increased dramatically. For this reason, frequent reinforcement of the unification of UTC is suggested early in the program. Successful mastery of the first few modules greatly enhances comprehension of later concepts.

APPENDIX A

MODULE SELECTION MATRIX

		NO. REQUIRED	TECHNOLOGIES	ENERGY USE AND CONSERVATION						LASER/ELECTRO-OPTICS							
S1	Formula Interpretation		X							X							
S2	International System of Units		X							X							
S3	Logarithms and Exponents		X							X							
S4	Angles and Triangles		X							X							
S5	Vectors and Scalars		X							X							
S6	Dimensional Analysis		X							X							
S7	Reading and Drawing Graphs		X							X							
S8	Precision, Accuracy, and Measurement		X							X							
1-0	FORCE		X							X							
1M1*	Gravity		X														
1M2*	Addition of Mechanical Forces		X							X							
1M3*	Addition of Torques		X							X							
1M4	Mechanical Equilibrium in Structures																
1M5*	Stress and Strain																
1M6	Tension in Wires and Cables		X														
1F1*	Atmospheric Pressure		X														
1F2*	Density, Buoyancy, and Specific Gravity		X							X							
1F3	Hydraulic Jack																
1F4	Manometers		X														
1E1*	Potential Difference and Charge Flow																
1E2	Series and Parallel Voltage Sources																
1E3*	Electric Forces and Fields		X							X							
1E4*	Magnetic Forces and Fields		X							X							
1E5	Lead-Acid Storage Battery																
1T1	Thermometers		X							X							
1T2*	Temperature Difference and Heat Flow		X							X							
1T3*	Thermal Stress									X							
2-0	WORK		X							X							
2M1	Work Done on an Elevator		X														
2M2	Work Done by a Winch																
2F1	Work Done by a Water Pump		X							X							
2F2	Work Done by a Hydraulic Lift																
2T1	Heat Energy Required for a Temperature Increase		X							X							
2T2	Heat Energy Required for Melting									X							
2T3	Heat Energy Required for Boiling									X							
2T4	Fundamentals of Air Conditioning		X							X							
3-0	RATE		X							X							
3M1*	Graphic Approach to Linear Motion																
3M2*	Velocity at Constant Acceleration		X							X							
3M3*	Displacement at Constant Acceleration		X							X							
3M4*	Acceleration of a Mass by Constant Force																
3M5*	Rotational Motion		X							X							

*Application Modules introducing new physics.

		NO. REQUIRED														
		TECHNOLOGIES	ENERGY USE AND CONSERVATION						LASER/ELECTRO-OPTICS							
3M6*	Radial Acceleration and Centripetal Force															
3F1	Flow Rate Measurement with a Venturi Meter															
3E1*	Electric Current	X							X							
3E2	Frequency	X							X							
3T1*	Heating and Cooling Rate															
3T2*	Rate of Heat Conduction	X							X							
4-0	MOMENTUM								X							
4M1	Angular Momentum of a Flywheel															
4M2	Impulse and Momentum															
4M3*	Conservation of a Momentum in Collisions								X							
4M4*	Gyroscopes															
4F1	Rocket Engines															
5-0	RESISTANCE	X							X							
5M1	Static and Sliding Friction															
5M2	Effect of Lubricants	X							X							
5M3	Rolling Friction	X							X							
5F1*	Laminar and Turbulent Flow															
5F2	Viscosity	X							X							
5F3*	Fluid Resistance in Pipes	X							X							
5F4	Valves and Regulators	X							X							
5F5	Shock Absorbers															
5F6	Drag-Resistance to Motion Through Fluids															
5E1	Ohm's Law	X							X							
5E2	Series and Parallel Resistors	X							X							
5E3	Internal Resistance of a Battery															
5E4*	Conductors, Semiconductors, and Insulators	X							X							
5E5*	Resistance of Wires	X							X							
5E6*	Resistance of Semiconductor Junctions	X														
5E7*	Resistance of Gas Laser Tubes								X							
5E8	Volt-Ohm Milliammeter	X							X							
5T1*	Thermal Conductivity								X							
5T2	Heat Flow Through Insulation	X														
6-0	POWER	X							X							
6M1	Horsepower															
6M2	Prony Brake	X														
6F1	Hydraulic Power	X							X							
6E1	Electrical Power Measurement	X							X							
6E2	Electric Heater															
6E3	Efficiency of Electric Motors and Generators	X														
6E4	Electrical Power Consumption	X							X							
6T1	Heat Exchangers	X							X							

		NO. REQUIRED																	
		TECHNOLOGIES	ENERGY USE AND CONSERVATION						LASER/ELECTRO-OPTICS										
7-0	POTENTIAL AND KINETIC ENERGY	X							X										
7M1	Piledriver																		
7M2	Potential Energy of a Spring																		
7M3	Rotational Kinetic Energy of a Flywheel	X																	
7M4*	Conservation of Energy in Collisions								X										
7M5	Kinetic Energy and Horsepower of an Automobile																		
7F1	Energy Stored in Large Tanks								X										
7F2	Venturi Meters	X							X										
7F3	Pitot Tubes	X																	
7F4	Energy Conversion in Fluid Systems																		
7F5*	Gas Laws																		
7F6	Siphons																		
7E1	Energy Stored in a Battery																		
7E2	Energy Stored in a Capacitor	X							X										
7E3*	Energy Stored in an Inductor	X							X										
7E4	Series and Parallel Capacitors	X							X										
7T1	Heat Storage Systems								X										
7T2*	Electrical Equivalent of Heat								X										
7T3*	Mechanical Equivalent of Heat								X										
7T4	Thermal Drying																		
7T5*	Mixing Liquids at Different Temperatures								X										
8-0	FORCE TRANSFORMERS	X							X										
8M1	Levers	X							X										
8M2	Wedges and Inclined Planes																		
8M3	Drive Systems	X							X										
8M4	Gear Trains	X																	
8M5	Block and Tackle																		
8M6	Differential Hoist																		
8F1	Hydraulic Press	X																	
8E1	Electrical Transformers	X							X										
9-0	ENERGY CONVERTOAS	X							X										
9F1	Turbines	X							X										
9F2	Fluid Pumps	X							X										
9F3	Wind Power	X																	
9F4	Fans and Blowers	X							X										
9F5	Vacuum Pumps	X							X										
9E1	Electric Generators	X							X										
9E2	Alternators	X																	
9E3	Electric Motors	X							X										
9E4	Solenoids and Relays	X							X										
9E5*	Photovoltaic Materials	X							X										
9T1	Boilers	X																	
9T2	Thermoelectric Generators	X																	
9T3	Solar Collectors	X							X										

		NO. REQUIRED	TECHNOLOGIES	ENERGY USE AND CONSERVATION					LASER/ELECTRO-OPTICS								
10-0	TRANSDUCERS		X						X								
10M1	Strain Gages		X						X								
10M2	Accelerometers		X														
10F1	Bourdon Tubes		X														
10F2	Aneroid Barometers																
10F3	Differential Pressure Transducers								X								
10F4	Fluid-Flow Measuring Devices								X								
10F5	Vacuum Gages		X						X								
10E1	Meter Movements		X						X								
10T1	Automobile Thermostats																
10T2	Bimetallic Strips		X						X								
10T3	Temperature Measuring Devices		X						X								
10T4	Thermocouples								X								
10T5	Thermistors		X						X								
10T6	Pyrometers																
11-0	VIBRATIONS AND WAVES		X						X								
11M1	Speed of Sound in Materials								X								
11M2	Reflection and Absorption of Sound Energy																
11M3	Vibration Isolation		X						X								
11M4*	Resonance																
11M5	Sound Speakers																
11F1*	Cavity Vibrations and Standing Waves		X						X								
11F2	Speaker Enclosures																
11F3	Reverberation Time																
11F4*	Doppler Effect								X								
11F5*	Pressure Measurement of Sound Waves		X														
11E1*	Alternating Voltage and Current		X						X								
11E2*	Phase Relationships in a.c. Circuits		X						X								
11E3	Oscilloscope		X						X								
11E4*	Rectifiers		X						X								
11E5	Electronic Filtering in d.c. Power Supplies		X						X								
11E6	Electronic Filtering for Frequency Selection								X								
11E7	Modulation of Electrical Waves								X								
12-0	TIME CONSTANTS		X						X								
12M1	Shock Isolation by Absorbers																
12F1	Rate of Emptying Tanks		X						X								
12E1	RC Circuits		X						X								
12E2	RL Circuits								X								
12E3*	RLC Circuits								X								
12T1	Response Time of Thermocouples		X						X								
12T2	Time Constants of Heating and Cooling		X						X								

		NO. REQUIRED													
		TECHNOLOGIES	ENERGY USE AND CONSERVATION					LASER/ELECTRO-OPTICS							
13-0	RADIATION	X						X							
13L1*	Inverse Square Law — Spreading of Light	X						X							
13L2*	The Optical Spectrum	X						X							
13L3	Light Sources	X						X							
13L4*	Lasers	X													
13L5	Stroboscopes — Light Pulses	X													
13L6*	Optical Filters — Absorption of Light	X						X							
13L7*	Specular and Diffuse Reflection of Light	X													
13L8*	Image Formation with Mirrors	X						X							
13L9*	Prisms — Refraction and Dispersion of Light	X						X							
13L10*	Lenses — Focusing and Spreading of Light	X						X							
13L11*	Interference — Testing Flat Surfaces							X							
13L12*	Diffraction Grating — Measuring the Wavelengths of Light							X							
13L13*	Polarization — Glare Reduction														
13L14	Holography — Three Dimensional Photography														
13L15	Spectroscopy — Light Analysis							X							
13L16	Infrared Radiation Thermometers	X													
13L17*	Illumination	X													
13L18	Single Lens Reflex Camera							X							
13N1	Geiger Counters														
13N2*	Penetrating Power of Alpha and Beta Radiation														
13N3*	Radioactivity														
13N4	Absorption of Gamma Radiation														

APPENDIX B

CONCEPT MODULE CHARTS

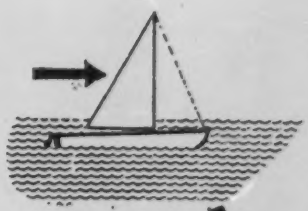
CONCEPT 1 - 0

FORCE

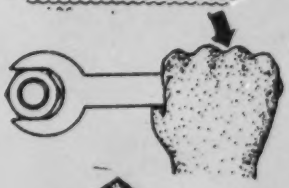
FORCELIKE QUANTITIES CAUSE MOVEMENT OF MASS, CHARGE OR ENERGY

MECHANICAL

TRANSLATIONAL: FORCE CAUSES LINEAR DISPLACEMENT OF MASS



ROTATIONAL: TORQUE CAUSES ANGULAR DISPLACEMENT OF MASS



FLUIDAL

PRESSURE DIFFERENCE CAUSES DISPLACEMENT OF VOLUME OF FLUID

ELECTRICAL

POTENTIAL DIFFERENCE CAUSES DISPLACEMENT OF CHARGE

THERMAL

TEMPERATURE DIFFERENCE CAUSES DISPLACEMENT OF HEAT ENERGY

CONCEPT 2 - 0

WORK

WORK RESULTS WHEN A FORCELIKE QUANTITY CAUSES A DISPLACEMENT.
THE UNIFYING EQUATION FOR WORK IS -

WORK DONE = ENERGY TRANSFERRED

WORK = FORCELIKE QUANTITY x DISPLACEMENTLIKE QUANTITY

MECHANICAL

TRANSLATIONAL: WORK = FORCE x DISPLACEMENT

ROTATIONAL: WORK = TORQUE x ANGLE OF ROTATION

FLUIDAL

WORK = PRESSURE DIFFERENCE x FLUID VOLUME DISPLACED

ELECTRICAL

WORK = POTENTIAL DIFFERENCE x CHARGE TRANSFERRED

THERMAL

HEAT ENERGY TRANSFERRED TO AN OBJECT
WHEN TEMPERATURE INCREASES:

HEAT ENERGY = TEMPERATURE CHANGE x HEAT CAPACITY

CONCEPT 3 - 0

RATE

RATE IS THE RATIO OF THE CHANGE IN A DISPLACEMENTLIKE QUANTITY TO THE TIME REQUIRED FOR THAT CHANGE.
THE UNIFYING EQUATION FOR RATE IS -

$$\text{RATE} = \frac{\text{DISPLACEMENTLIKE QUANTITY}}{\text{ELAPSED TIME}}$$

MECHANICAL

TRANSLATIONAL

$$\text{VELOCITY} = \frac{\text{DISPLACEMENT}}{\text{ELAPSED TIME}}$$

$$\text{ACCELERATION} = \frac{\text{CHANGE IN VELOCITY}}{\text{ELAPSED TIME}}$$

ROTATIONAL

$$\text{ANGULAR VELOCITY} = \frac{\text{ANGULAR DISPLACEMENT}}{\text{ELAPSED TIME}}$$

$$\text{ANGULAR ACCELERATION} = \frac{\text{CHANGE IN ANGULAR VELOCITY}}{\text{ELAPSED TIME}}$$

FLUIDAL

$$\text{VOLUME FLOW RATE} = \frac{\text{VOLUME DISPLACED}}{\text{ELAPSED TIME}}$$

$$\text{MASS FLOW RATE} = \frac{\text{MASS DISPLACED}}{\text{ELAPSED TIME}}$$

ELECTRICAL

$$\text{CURRENT} = \frac{\text{CHARGE TRANSFERRED}}{\text{ELAPSED TIME}}$$

THERMAL

$$\text{HEAT FLOW RATE} = \frac{\text{HEAT ENERGY TRANSFERRED}}{\text{ELAPSED TIME}}$$

CONCEPT 4 - 0

MOMENTUM

MOMENTUM DESCRIBES THE TENDENCY OF MOVING MASS TO CONTINUE ITS MOTION WITHOUT CHANGE UNLESS A FORCELIKE QUANTITY ACTS UPON IT. IMPULSE IS THE PRODUCT OF THE FORCELIKE QUANTITY AND THE TIME DURING WHICH IT ACTS. THE UNIFYING EQUATIONS FOR IMPULSE AND MOMENTUM ARE -

MOMENTUM = INERTIA X RATE
IMPULSE = FORCELIKE QUANTITY X ELAPSED TIME
IMPULSE = CHANGE IN MOMENTUM

MECHANICAL

TRANSLATIONAL

MOMENTUM = MASS x VELOCITY

IMPULSE = FORCE x TIME

ROTATIONAL

ANGULAR MOMENTUM = MOMENT OF INERTIA x ANGULAR VELOCITY

ANGULAR IMPULSE = TORQUE x TIME

FLUIDAL

MOMENTUM = MASS x VELOCITY

THE CONCEPT OF MOMENTUM IS NOT APPLIED TO ELECTRICAL OR THERMAL SYSTEMS

CONCEPT 5 - 0

RESISTANCE

RESISTANCE IS AN OPPOSITION TO MOTION AND CAUSES MOTION TO EVENTUALLY CEASE IF NO FORCELIKE QUANTITIES ARE PRESENT TO SUSTAIN IT.

MECHANICAL

UNLIKE OTHER FORMS OF RESISTANCE, FRICTION IS NOT DEPENDENT UPON RATE.

FRICTIONAL FORCE = COEFFICIENT OF FRICTION X NORMAL FORCE

THE UNIFYING EQUATION FOR OTHER TYPES OF RESISTANCE IS-

$$\text{RESISTANCE} = \frac{\text{FORCELIKE QUANTITY}}{\text{RATE}}$$

FLUIDAL

$$\text{RESISTANCE} = \frac{\text{PRESSURE DIFFERENCE}}{\text{FLOW RATE}}$$

ELECTRICAL

$$\text{RESISTANCE} = \frac{\text{VOLTAGE}}{\text{CURRENT}}$$

THERMAL

$$\text{RESISTANCE} = \frac{\text{TEMPERATURE DIFFERENCE}}{\text{HEAT FLOW RATE}}$$

THE ENERGY USED TO OVERCOME RESISTANCE IN MECHANICAL, FLUIDAL, AND ELECTRICAL SYSTEMS IS CONVERTED INTO HEAT

CONCEPT 6 - 0

POWER

POWER IS THE RATE OF DOING WORK. THE UNIFYING EQUATIONS OF POWER ARE-

$$\text{POWER} = \frac{\text{WORK (ENERGY)}}{\text{TIME ELAPSED}} \quad \text{OR} \quad \text{POWER} = \text{FORCELIKE QUANTITY} \times \text{RATE}$$

MECHANICAL

TRANSLATIONAL:

$$\text{POWER} = \frac{\text{MECHANICAL WORK}}{\text{TIME}}$$

$$\text{POWER} = \text{FORCE} \times \text{VELOCITY}$$

ROTATIONAL:

$$\text{POWER} = \frac{\text{MECHANICAL WORK}}{\text{TIME}}$$

$$\text{POWER} = \text{TORQUE} \times \text{ANGULAR VELOCITY}$$

FLUIDAL

$$\text{POWER} = \frac{\text{FLUIDAL WORK}}{\text{TIME}}$$

$$\text{POWER} = \text{PRESSURE} \times \text{FLOW RATE}$$

ELECTRICAL

$$\text{POWER} = \frac{\text{ELECTRICAL WORK}}{\text{TIME}}$$

$$\text{POWER} = \text{VOLTAGE} \times \text{CURRENT}$$

THERMAL

$$\text{POWER} = \frac{\text{HEAT ENERGY}}{\text{TIME}}$$

CONCEPT 7 - 0

POTENTIAL AND KINETIC ENERGY

POTENTIAL ENERGY IS THE ENERGY OF POSITION. KINETIC ENERGY IS THE ENERGY OF MOVING MASS. THE FOLLOWING ARE EXAMPLES OF POTENTIAL AND KINETIC ENERGY:

MECHANICAL

POTENTIAL ENERGY

GRAVITATIONAL: $E_P = mgh$

SPRING: $E_P = 1/2\ kx^2$

KINETIC ENERGY

TRANSLATIONAL: $E_K = 1/2\ mv^2$

ROTATIONAL $E_K = 1/2\ I\omega^2$

FLUIDAL

GRAVITATIONAL POTENTIAL ENERGY $E_P = (\rho V)gh$

KINETIC ENERGY $E_K = 1/2\ (\rho V)v^2$

ELECTRICAL

POTENTIAL ENERGY STORED IN A CAPACITOR $E_P = 1/2\ CV^2$

THERMAL

THERMAL ENERGY IS THE KINETIC ENERGY OF MOVING MOLECULES

THE PRINCIPLE OF CONSERVATION OF ENERGY STATES THAT THE FORM OF ENERGY MAY BE CHANGED BUT ENERGY CAN BE NEITHER CREATED NOR DESTROYED. THE TOTAL ENERGY OF A CLOSED SYSTEM IS CONSTANT.

CONCEPT 8 - 0

FORCE TRANSFORMERS

FORCE TRANSFORMERS ARE DEVICES THAT TRANSFORM FORCELIKE QUANTITIES AND DISPLACEMENTLIKE QUANTITIES. THE UNIFYING EQUATION FOR FORCE TRANSFORMERS IS-

ENERGY IN = ENERGY OUT

OR

INPUT FORCELIKE QUANTITY x INPUT DISPLACEMENTLIKE QUANTITY = OUTPUT FORCELIKE QUANTITY x OUTPUT DISPLACEMENTLIKE QUANTITY

MECHANICAL

TRANSLATIONAL: FORCE IN x DISPLACEMENT IN = FORCE OUT x DISPLACEMENT OUT

ROTATIONAL: TORQUE IN x ANGULAR DISPLACEMENT IN = TORQUE OUT x ANGULAR DISPLACEMENT OUT

FLUIDAL

FORCE IN x DISPLACEMENT IN =
FORCE OUT x DISPLACEMENT OUT

ELECTRICAL

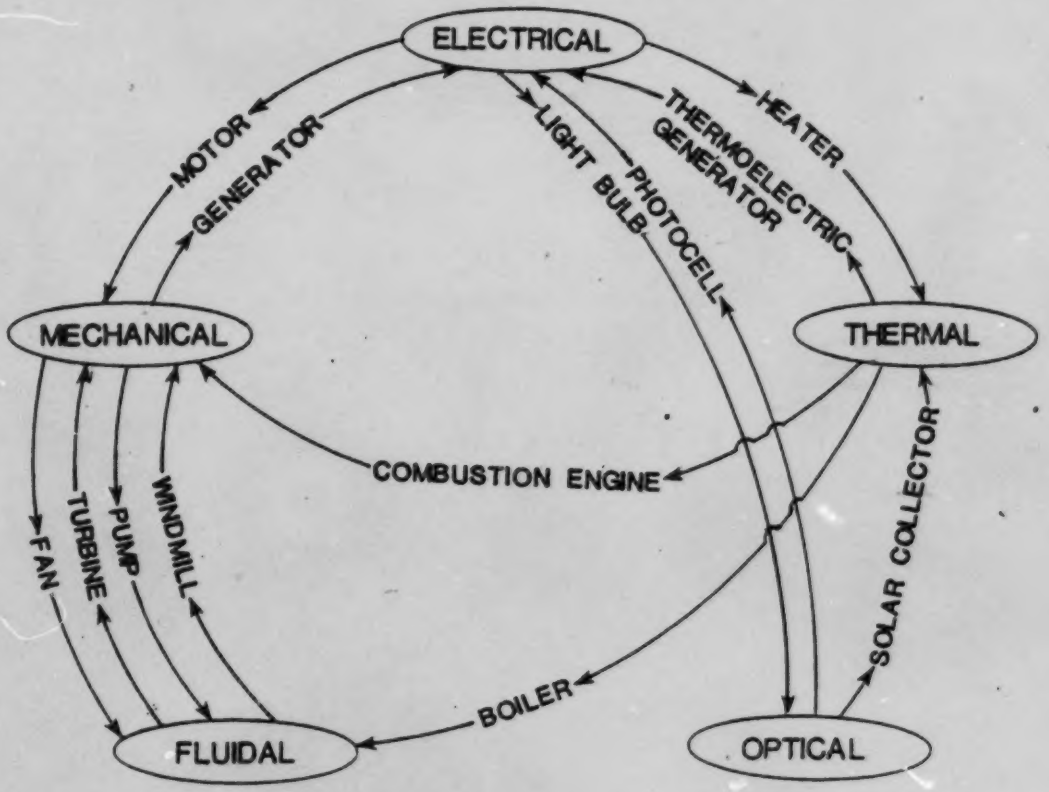
VOLTAGE IN x CURRENT IN =
VOLTAGE OUT x CURRENT OUT

THE CONCEPT OF FORCE TRANSFORMERS IS NOT APPLIED TO THERMAL SYSTEMS.

CONCEPT 9 - 0

ENERGY CONVERTORS

ENERGY CONVERTORS ARE DEVICES THAT CHANGE ENERGY IN ONE FORM (ENERGY SYSTEM) TO ENERGY IN ANOTHER FORM.

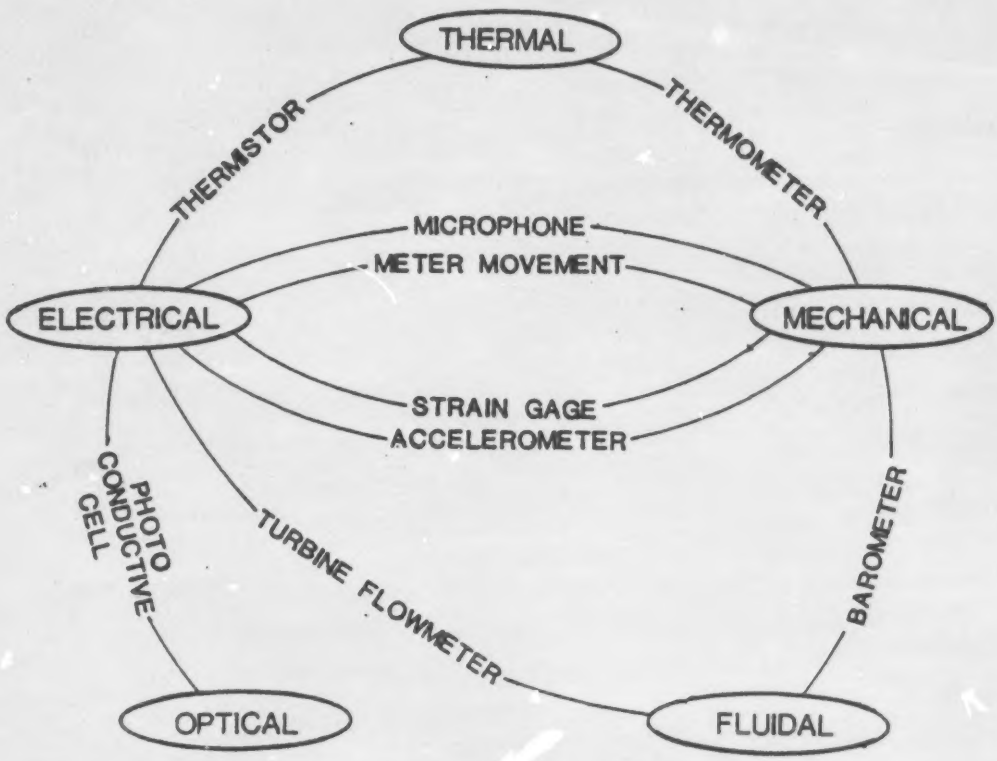


ALL ENERGY CONVERTORS CHANGE A PART OF THE INPUT ENERGY TO WASTE HEAT.

CONCEPT 10 - 0

TRANSDUCERS

TRANSDUCERS ARE DEVICES THAT CONVERT INFORMATION-CARRYING SIGNALS FROM ONE ENERGY SYSTEM TO ANOTHER. MOST TRANSDUCERS PRODUCE PRODUCE ELECTRICAL OR MECHANICAL OUTPUTS.



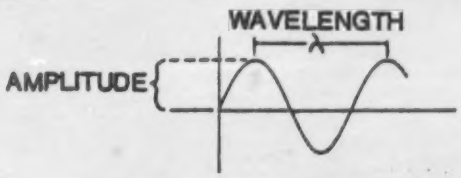
CONCEPT 11 - 0

VIBRATIONS AND WAVES

A WAVE IS A DISTURBANCE IN WHICH ENERGY IS TRANSMITTED FROM ONE LOCATION TO ANOTHER.

VELOCITY $v = \lambda/T$

$v \quad \lambda f$

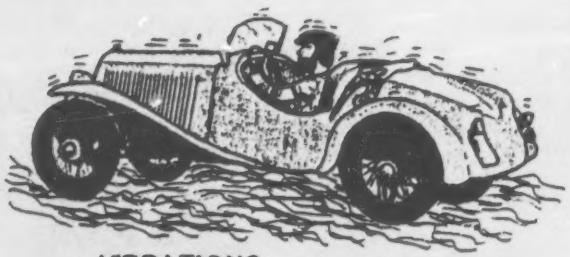


PERIOD: T = TIME FOR ONE CYCLE

FREQUENCY: F = NUMBER OF CYCLES IN ONE SECOND

THE FOLLOWING ARE EXAMPLES OF WAVES:

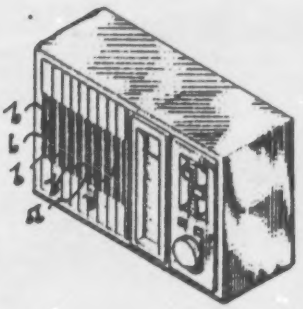
MECHANICAL



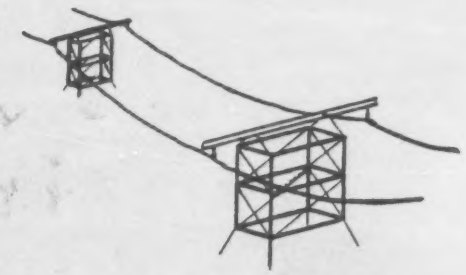
VIBRATIONS

FLUIDAL

SOUND

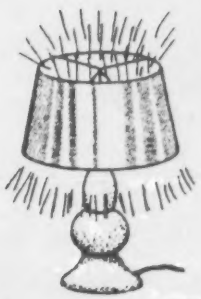


ELECTRICAL



A.C. POWER

OPTICAL

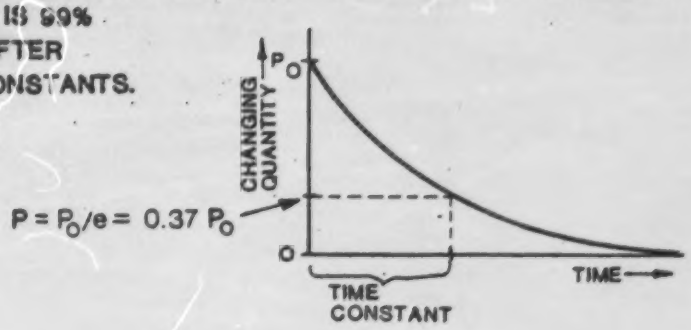


LIGHT

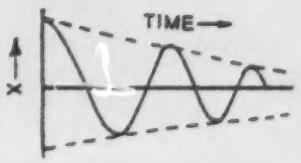
CONCEPT 12 - 0

TIME CONSTANTS

WHEN A PHYSICAL SYSTEM IS CHANGING WITH TIME BUT IS APPROACHING A STEADY STATE, RATES IN THAT SYSTEM DIMINISH EXPOTENTIALLY. THE TIME CONSTANT OF THE SYSTEM IS THE TIME REQUIRED FOR THE CHANGE TO BE 63% COMPLETE. THE CHANGE IS 99% COMPLETE AFTER FIVE TIME CONSTANTS.

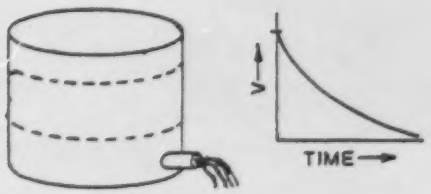


MECHANICAL



DAMPED OSCILLATIONS

FLUIDAL



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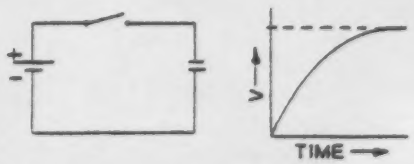
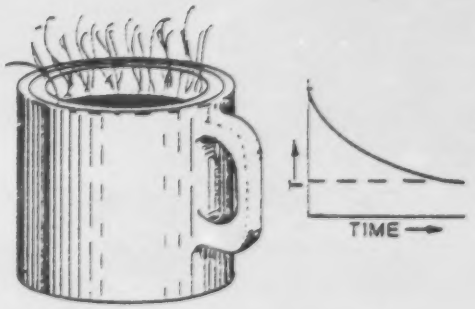


CHARGING CAPACITORS

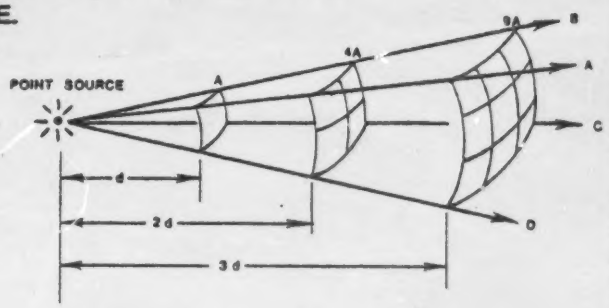
THERMAL



CONCEPT 13 - 0

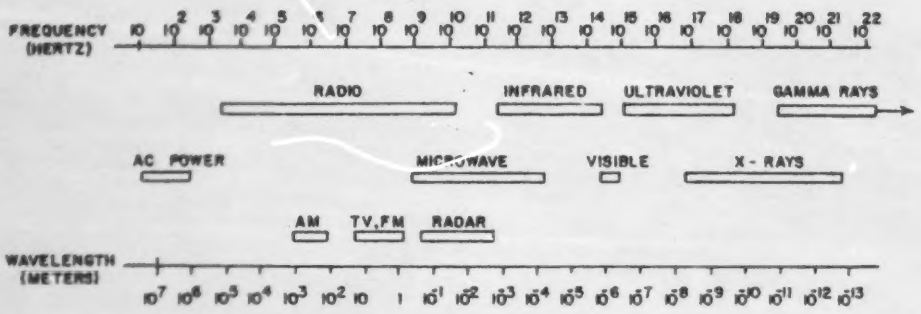
RADIATION

RADIATION IS THE PROCESS BY WHICH ENERGY MOVES AWAY FROM A SOURCE IN A STRAIGHT LINE. THE INVERSE SQUARE LAW STATES THAT THE INTENSITY OF RADIATION AT ANY POINT IS INVERSELY PROPORTIONAL TO THE SQUARE OF THE DISTANCE FROM THE SOURCE.



TWO TYPES OF PHENOMENA ARE OFTEN CLASSED AS "RADIATION"

ELECTROMAGNETIC RADIATION



PARTICLE RADIATION

RADIOACTIVE ATOMS MAY RELEASE TWO TYPES OF PARTICLES WHEN THEY DECAY. ALPHA PARTICLES CONSIST OF TWO PROTONS AND TWO NEUTRONS-A HELIUM NUCLEUS. BETA PARTICLES ARE ENERGETIC ELECTRONS EJECTED FROM THE NUCLEUS.

APPENDIX C

MODULE SUMMARIES

SUPPLEMENTARY MODULES

S1, FORMULA INTERPRETATION

This module discusses mathematics as the language of physics and presents formulas as mathematical models used to explain and to predict events in the physical universe. Basic algebraic techniques used to solve equations with a single unknown are presented with formulas from other UTC modules as examples. Topics discussed include ratios, proportions, powers and roots, and problem-solving techniques. Expressions involving trigonometry, logarithms, and exponentials are covered in other modules. In the laboratory, the student will solve equations for indicated variables.

Prerequisites: One year of high school algebra.

S2, INTERNATIONAL SYSTEM OF UNITS

This module discusses the International System of Units. It includes explanations of base, supplementary, and derived units of the SI system. The proper use of prefixes and the proper notations for stating quantities in SI units are included. This module also discusses the units not in the SI system that may be used with SI units and the conversion from SI to English units. A pencil-and-paper laboratory exercise is provided to give the student practical experience in manipulating SI units.

Prerequisites: One year of high school algebra.

S3, LOGARITHMS AND EXPONENTS

This module discusses the use of logarithms and powers of ten in solving problems in physics. Topics presented include the writing of numbers using powers of ten, significant figures, mathematical operations on numbers using powers of ten, exponential and logarithmic notations, common and natural logarithms, the use of log tables, and methods of solving logarithmic and exponential equations. Pencil-and-paper exercises provide the student with practice in using the techniques discussed.

Prerequisites: One year of high school algebra.

S4, ANGLES AND TRIANGLES

This module introduces angles and their measurement to the extent necessary to understand their use in triangles of several different types. Similar triangles, right triangles, and the Pythagorean theorem are presented. Trigonometric ratios of sine, cosine, and tangent are discussed. Protractors, metric scales, and an optional electronic calculator are used in the laboratory.

Prerequisites: One year of high school algebra.

S5, VECTORS AND SCALARS

Scalars and vectors are examined in this module; they are distinguished carefully from each other. Different methods of examining them are outlined in detail. The laboratory exercise consists of the drawing and the resolving of vectors.

Prerequisites: One year of high school algebra.

S6, DIMENSIONAL ANALYSIS

In this support module, the method of handling units in calculations (dimensional analysis) is presented in order that the units will reinforce the physics principles and assist in the problem-solving process. The advantages of dimensional analysis are presented, along with some of the techniques for handling units in calculations, as well as four working examples. The laboratory involves calculations and conversions with dimensional analysis.

Prerequisites: One year of high school algebra.

S7, READING AND DRAWING GRAPHS

This module discusses the use of graphs in presenting data. Methods of reading graphs, calculating slopes, and determining areas under curves are included. Some typical applications of graphs are provided. Pencil-and-paper exercises provide the student with practice in interpreting and preparing graphs similar to those found in other UTC modules.

Prerequisites: One year of high school algebra.

S8, PRECISION, ACCURACY, AND MEASUREMENT

This module discusses distinction between counting and measuring and factors affecting the measuring process. Topics include standards of measurement, precision and accuracy, calculating and stating limits of errors, direct and indirect measurements, and random and systematic errors in measurement. The proper techniques of measuring length with linear, vernier, and micrometer instruments are included. These techniques are used in a laboratory exercise, in which students analyze precision and accuracy of length measurements.

Prerequisites: One year of high school algebra.

1-0 FORCE

This module discusses the concept of force and forcelike quantities as they apply to four energy systems — mechanical, fluidal, electrical, and thermal. The forcelike quantities as discussed are force, torque, pressure, voltage, and temperature difference.

- Force causes motion of an object in a translational mechanical system. This force serves as the model for all forcelike quantities.
- Torque causes rotation of an object in a rotational mechanical system. Torque is a forcelike quantity.
- Pressure causes a fluid to move in a fluidal system. Pressure is a forcelike quantity.
- Voltage causes electrical charge to move in an electrical system. Voltage is a forcelike quantity.
- Temperature difference causes heat energy to move in a thermal system. Temperature difference is a forcelike quantity.

The following laboratory demonstrations are included: (1) Sliding wood blocks demonstrate that forces in mechanics cause motion. (2) Rotational motion is illustrated with a torque wrench. (3) A manometer is used to demonstrate force in the fluidal system. (4) The thermal system is exhibited in the form of a metal rod heated at one end until heat is "observed" to flow toward the cool end, where wax is melted on the rod.

Prerequisites: One year of high school algebra.

1M1, GRAVITY

The relationship between gravitational force and acceleration of free-falling objects is discussed. In the laboratory, weight and mass of several objects are determined; use is made of balances and scales.

Prerequisites: 1-0.

1M2, ADDITION OF MECHANICAL FORCES

In this application module, mathematical and graphical explanations of concurrent coplanar forces are discussed. Various vector relationships are presented, including two at right angles, two not at right angles, two on the same line in the same and opposite direction, and the resultant of more than two forces. A laboratory procedure using a scale and a force table enables the student to solve a series of force problems and to calculate the magnitude and direction of resultants.

Prerequisites: 1-0.

1M3, ADDITION OF TORQUES

This application module, as an extension of 1M2, examines what happens when all forces do not act through a single point. Two conditions for equilibrium are given, and explanations are given when $\Sigma F \neq 0$ and $\Sigma \tau \neq 0$. In the laboratory, the student will determine the mass of an object from the forces applied to it, and will determine the position required to balance it, or bring it to equilibrium.

Prerequisites: 1-0, 1M2.

1M4, MECHANICAL EQUILIBRIUM IN STRUCTURES

The applications of load-distribution examples are described. Trusses, gates, and crane booms are used as illustrations of force distribution and torque-absorbing members. Practical examples found in everyday situations are provided and solved. A procedure involving nine cases of a simulated crane boom system enables the student to measure and to calculate loads and angles.

Prerequisites: 1-0, 1M2, 1M3.

1M5, STRESS AND STRAIN

In this application module, a detailed look at stress and strain is made by examining Hooke's law, elasticity, deflection, shear modulus, twist, and bulk modulus. Experiments are provided to illustrate these aspects of stress and strain. Definitions of stress, strain, Hooke's law, elastic limit, yield point, breaking point, modulus of elasticity, shear modulus, bulk modulus, safety factor, and ultimate breaking strength are given. Procedures whereby the student measures Hooke's law values for brass, copper, aluminum, ultimate tensile strength for brass, copper, and aluminum wire, and deflections of a wooden beam are included.

Prerequisites: 1-0, 1M2.

1M6, TENSION IN WIRES AND CABLES

Tension and its general characteristics and applications are examined. The tension in weighted flexible lines also is presented in the discussion section and is the subject of the laboratory experiment.

Prerequisites: 1-0, 1M2.

1F1, ATMOSPHERIC PRESSURE

In this application module air-pressure magnitude and measurements is described by use of manometers and mercury and aneroid barometers. Boyle's law apparatus is used to demonstrate through experiments the effects of air pressure. A table of various units for standard pressure and four worked examples are included. Procedures enable the student to construct a mercury barometer and to measure and calculate pressure and volume of confined air (Boyle's law).
Prerequisites: 1-0.

1F2, DENSITY, BUOYANCY, AND SPECIFIC GRAVITY

This module introduces the methods of determining the density and specific gravity of fluids by means of floating objects placed within those fluids. Such suspended objects are acted upon by the downward force of gravity (weight) and by the upward buoyant force of the fluid. Specific gravity is applied in determining the amount of antifreeze in radiators, the amount of acid in batteries, etc. In the laboratory, the student will use a hydrometer to determine the specific gravity of several fluids.
Prerequisites: 1-0.

1F3, HYDRAULIC JACK

The hydraulic jack is an example of a force magnifier in a closed hydraulic system employing Pascal's law. By use of valves, a fluid reservoir, and pressure, large loads can be moved short distances with relative ease. Calculation of the input/output pressures are illustrated. The laboratory demonstrates this principle by use of disposable syringes.
Prerequisites: 1-0.

1F4, MANOMETERS

This module, basic to many later modules describes three types of manometers: U-tube, well, and inclined tube. The student will be introduced to the basic concepts of pressure measurement with manometers. Measurement of positive pressure, vacuum and differential pressure is illustrated. Industrial variations — the well-type manometer and the inclined manometer — also are presented. In the laboratory, the student will use a U-tube manometer to verify the calibration of a pressure gage.
Prerequisites: 1-0.

1E1, POTENTIAL DIFFERENCE AND CHARGE FLOW

This module discusses the origin of magnetic forces, the representation of magnetic forces in terms of magnetic fields, and the mapping of magnetic fields around bar magnets, horseshoe magnets, iron-core solenoids and long, straight wires. It also discusses how forces develop on current-carrying conductors in the presence of a magnetic field and how this principle is used in the construction of generators and motors. In the laboratory, the student will map magnetic fields, observe the results of forces upon current-carrying conductors in magnetic fields, and will construct and operate a simple electromagnet.
Prerequisites: 1-0.

1E2, SERIES AND PARALLEL VOLTAGE SOURCES

In this application module, the calculation and determination of emf's in linear and parallel circuits that have like and unlike poles connected are described. Examples of motor voltage calculation also are shown. Laboratory procedures enable the student to connect several different circuits and to measure voltages with a VOM across designated components.
Prerequisites: 1-0, 1E1.

1E3, ELECTRIC FORCES AND FIELDS

This module discusses magnetic forces between permanent magnetic and the magnetic forces affecting moving charges. The concepts of lines of magnetic force and magnetic fields are introduced and illustrated with permanent magnets and electromagnets. The relationship between charge, voltage, and capacitance also is presented. In the laboratory, the student will produce and describe line patterns of electric fields.
Prerequisites: 1-0.

1E4, MAGNETIC FORCES AND FIELDS

This module discusses the electric forces on charge particles due to a potential difference, lines of electric force, and the concept of the electric field as the ratio of change in potential to change in position. Examples include forces between like and unlike charges, electric fields produced by point charges, and electric fields in parallel-plate capacitors. The laboratory procedure allows the student to observe electrical forces, and a simple electromagnet is constructed and operated.
Prerequisites: 1-0, 1E3.

1E5, LEAD-ACID STORAGE BATTERY

The basic mechanisms of producing electrical energy in an acid battery are described. An automotive battery is examined in detail including the effect of changing to specific gravity and temperature and resulting electric potential output. Students are asked to construct, charge, and discharge a lead-acid storage cell.
Prerequisites: 1-0.

1T1, THERMOMETERS

The four temperature scales (Fahrenheit, Centigrade, Kelvin and Rankin) are compared, and conversion equations are provided. Also included are four temperature-sensing devices, including a thermocouple, gas thermometer, pyrometer, and liquid-in-glass types. Procedures enable the students to calibrate their own thermometer and to convert °F to °C.
Prerequisites: 1-0.

1T2, TEMPERATURE DIFFERENCE AND HEAT FLOW

In this application module, heat transmission by conduction, convection, and radiation is described. The movement of heat in an attempt to achieve thermal equilibrium also is discussed. Conduction experiments and methods of calculating conductivity of certain situations provide actual examples of the principles discussed. A laboratory procedure enables the student to measure the conductive properties of a portion of conducting material.
Prerequisites: 1-0.

1T3, THERMAL STRESS

In this application module, the mathematical and practical relationship of thermal expansion is expressed and described. A table of linear coefficients of expansion of several materials is provided. A procedure that demonstrates thermal expansion of a steel wire is included.
Prerequisites: 1-0.

2-0 WORK

Work is done in any physical system whenever a forcelike quantity causes a change (displacement-like quantity) within the system. Energy is the ability to do work, and is conserved within a closed system. When a system is in equilibrium, it contains energy, but no work is being done, because no displacement is occurring as the result of forcelike quantities within the system. When a system is not in equilibrium, displacement of some kind occurs as the result of forcelike quantities; and energy is converted to work within the system. Work and energy are equivalent and are measured in the same units.

Laboratory Demonstrations: (1) Work in the mechanical system is demonstrated by an object of known mass lifted a given distance. (2) Rotational work of a spinning gyroscope is analyzed. (3) A container is filled with fluid, and the work performed is determined. (4) Thermal and electrical work are demonstrated by a storage battery whose leads are connected through a small wire that generates heat in the water in which it is immersed.
Prerequisites: 1-0.

2M1, WORK DONE ON AN ELEVATOR

In this module, the mechanical work required to lift objects against the force of gravity is defined, and the inclined plane and its advantages in lifting are discussed. In the laboratory, the student will determine the work required to lift objects vertically and on an incline.
Prerequisites: 2-0.

2M2, WORK DONE BY A WINCH

This module presents an application of the concept of work in rotational systems, and describes in particular the rotational work into and out of a winch. Other topics discussed include the efficiency of winches, the use of geared winches and the effects of torque variations upon them. In the laboratory, the student will determine the work and efficiency of a winch.
Prerequisites: 2-0.

2F1, WORK DONE BY A WATER PUMP

In this module, the student will review principles of work and energy as they apply to fluids and electricity. Values for work and energy involving fluids and electricity will be derived experimentally and in problems. In the laboratory, the student will measure current and voltage supplied to a pump, and will calculate the work and efficiency of the pump.
Prerequisites: 2-0.

2F2, WORK DONE BY A HYDRAULIC LIFT

In this application module, a hydraulic lift is described with principles of industrial applications. Formulae are presented for input and output work in terms of mechanical, electrical, and pneumatic systems. A laboratory procedure enables the student to measure work through the use of a hydraulic jack.
Prerequisites: 2-0.

2T1, HEAT ENERGY REQUIRED FOR A TEMPERATURE INCREASE

This module introduces the use of the calorimeter for measurement of the thermal properties of materials. In the laboratory, the student will use a calorimeter (or experimental apparatus similar to a calorimeter) to measure some thermal properties of materials.
Prerequisites: 2-0.

2T2, HEAT ENERGY REQUIRED FOR MELTING

In this application module, examination is made of the energy requirements necessary to cause a change from solid to liquid state (heat of fusion). A table of melting points and heats of fusion of common solids and liquids is included. Working examples are provided. A procedure whereby the student can measure and calculate the heat of fusion is provided.
Prerequisites: 2-0.

2T3, HEAT ENERGY REQUIRED FOR BOILING

In this application module, the temperature of heated water as a function of time is measured, and the effect of heat of vaporization noted. Procedures for measurement of temperature-versus-time during boiling water and the cooling effect of an evaporating liquid are given for student completion.
Prerequisites: 2-0, 2T1.

2T4, FUNDAMENTALS OF AIR CONDITIONING

This application module includes definitions of heat-energy terms. A complete description of air conditioning principles and a schematic of a home air conditioner are provided. Energy Efficiency Ratios (EER's) are described and several common values included. An example of the cost comparison of several EER's is given. A laboratory procedure covering costs and efficiency of actual air conditioners is provided.
Prerequisites: 2-0.

3-0 RATE

This module presents the concept of rate as it applies to mechanical, fluidal, electrical, and thermal systems. In every case, rate expresses the ratio of a displacementlike quantity to an elapsed time:

- In a linear mechanical system, velocity is the ratio of distance traveled to elapsed time.
- In a rotational mechanical system, angular velocity is the ratio of angle of rotation to elapsed time.
- In a fluidal system, volume flow rate is the ratio of volume of fluid moved to elapsed time.
- In an electrical system, current is the ratio of charge transferred to elapsed time.
- In a thermal system, heat flow rate is the ratio of thermal energy transferred to elapsed time.

Laboratory Demonstrations: (1) Rate for mechanical systems is illustrated by a toy car, for which velocity and wheel speed are calculated. (2) For the fluid system, a water faucet is utilized to simulate discharge from a cooling system. (3) A conductometer is used to determine the rate of heat conduction for several materials. (4) Electric current is measured with an ammeter to determine rate of "flow."
Prerequisites: 2-0.

3M1, GRAPHICAL APPROACH TO LINEAR MOTION

The general subject of relationships between speed, position and time is called kinematics. In this module, only the description of motion along a straight line will be studied. Such motion is called rectilinear motion. A later module will concern present circular motion, which is somewhat more complicated. In the laboratory, the motion of an automobile is analyzed.
Prerequisites: 3-0.

3M2, VELOCITY AT CONSTANT ACCELERATION

This module provides problems that involve velocity and acceleration (constant acceleration) only to confom to the mathematical capabilities of the student. Working examples that cover acceleration, final speed, and time to reach a given speed are provided. A procedure in which the student measures the velocity of an object on a slope and straightaway track is given.
Prerequisites: 3-0.

3M3, DISPLACEMENT AT CONSTANT ACCELERATION

In this module, the student will learn that, given any three of the five motion parameters (displacement, initial velocity, final velocity, acceleration and time), the remaining two can be found. In the laboratory, the student will determine an acceleration down an incline and along a straightaway.
Prerequisites: 3-0, 3M2.

3M4, ACCELERATION OF A MASS BY CONSTANT FORCE

This module describes the relationship of force, mass, and acceleration; and it includes a discussion of displacement, initial velocity, final velocity, and time as parameters of motion. Construction of an Atwood's machine, a device used to determine the mass or acceleration of an object, also is discussed. In the laboratory, the student will use a pulley and other simple materials to construct an Atwood's machine and will determine the mass and acceleration of an object.
Prerequisites: 3-0, 3M2, 3M3.

3M5, ROTATIONAL MOTION

In this module, rotational motion is presented as the motion of a body that turns about an axis. Equations are presented that describe the relationship of angular displacement, angular velocity, and angular acceleration. In the laboratory, the student will use the equations and principles of rotational motion to determine the angular velocity and angular acceleration of a phonograph turntable.
Prerequisites: 3-0, 3M3.

3M6, RADIAL ACCELERATION AND CENTRIPETAL FORCE

Centripetal force is the inward force upon an object as it moves in a circular path. Radial, or centripetal, acceleration of an object is the change in its velocity divided by a time interval. Radial acceleration, centripetal force, and centrifugal force are discussed in this module, and the operation of governors and centrifugal pumps is examined. In the laboratory, the student will use a centripetal force apparatus to determine the radial acceleration and centripetal force of a rotating object.
Prerequisites: 3-0, 3M5.

3F1, FLOW RATE MEASUREMENT WITH A VENTURI METER

This module presents operating principles of a venturi flow meter, a typical device used in industry for accurate flow-rate measurements. An experiment is included to give the student hands-on experience in the use of a laboratory model of a venturi tube.
Prerequisites: 3-0.

3E1, ELECTRIC CURRENT

The concepts of direct and alternating current are examined. The laboratory exercise acquaints the student with important current measurements with a d.c. ammeter and with an a.c. ammeter.
Prerequisites: 3-0.

3E2, FREQUENCY

Frequency and time relate to each other in repetitive events. The importance of known frequencies for time measurement is noted, as well as the concept of spatial frequency. In the laboratory, the student will measure electrical frequencies with an oscilloscope; will measure the period of a pendulum; and will use a laser in determining the spatial frequency of the grooves in a diffraction grating.
Prerequisites: 3-0.

3T1, HEATING AND COOLING RATE

This module presents the rate of heating and cooling as change in temperature divided by time. Examples of the calculation of cooling/heating rates are presented, and a graphical presentation is made. A procedure provides the student with the capability of measuring and plotting heating rate.
Prerequisites: 3-0.

3T2, RATE OF HEAT CONDUCTION

This module treats the rate of heat conduction through solid materials, taking into account the physical quantities affecting rate, and relating them through a coefficient of thermal conductivity or an average coefficient of heat transmission. The use of insulation in reducing the rate of heat conduction is emphasized. In the laboratory, the student will determine the rate of heat conduction for several materials.
Prerequisites: 3-0.

4-0 MOMENTUM

Moving objects possess a very important physical quantity called "momentum." "Linear momentum," a vector quantity, depends upon the mass and the linear velocity of the object. "Angular momentum," also a vector quantity, depends upon the moment of inertia and the angular velocity of a rotating mass. This module explains the mathematical relationships involved with both linear and angular momentum. Elastic and inelastic collisions are considered, as well as "the law of conservation of momentum."

Laboratory Demonstrations: (1) Linear momentum is demonstrated by use of an air tract or by dry-ice pucks. (2) Angular momentum of a rotating platform or stool is observed. (3) Elastic and inelastic collisions are exhibited by a number of spheres (each of a different material) dropped on a steel base.
Prerequisites: 3-0.

4M1, ANGULAR MOMENTUM OF A FLYWHEEL

An examination of several rotating systems and their calculation is presented. A table of the analog between translational and rotational quantities is given, as well as several examples for the calculation of the angular momentum of discs. A procedure for the experimental calculation of flywheel-type device is provided.
Prerequisites: 4-0.

4M2, IMPULSE AND MOMENTUM

Impulse is the product of force and the duration of application of the force. An impulse applied to a mass causes a change in momentum of the mass. This module discusses impulse and change in momentum as it applies to mechanical components and systems of modern technology. In the laboratory, the student will measure impluse and change in momentum.
Prerequisites: 4-0.

4M3, CONSERVATION OF MOMENTUM IN COLLISIONS

In this module, momentum conservation is applied to elastic and inelastic collisions. In the laboratory, the student will analyze both elastic and inelastic collisions in one dimension to verify conservation of momentum. An air track and two air carts are employed in the laboratory.
Prerequisites: 4-0.

4M4, GYROSCOPES

In this module, the student will learn how the properties of the gyroscope depend upon torque and angular momentum. The student will solve problems involving these parameters and gain an understanding of the vector nature of the gyroscopic effect. In the laboratory, the student will observe the effects of external forces on a spinning gyroscope. The student will also use the gyroscopic effect to determine the angular momentum of a spinning gyroscope. Finally, the student will construct a simple gyrocompass.
Prerequisites: 4-0, 1M3, 1M4.

4F1, ROCKET ENGINES

The general characteristics of rocket propulsion are discussed, and the concepts of momentum and impulse are applied to the performance of rocket engines. An experiment provides a hands-on test of the impulse produced by ignition of a solid-fuel model rocket engine.

Prerequisites: 4-0.

5-0 RESISTANCE

This module discusses (1) the phenomenon referred to in a general way as "resistance" and (2) the application of the concept of resistance to mechanical, fluidal, electrical, and thermal systems. The discussion includes the similarities of resistance in all energy systems. These similarities make resistance a unifying concept. The discussion also includes the differences in resistance characteristics from one system to another.

Laboratory Demonstrations: (1) Dry friction of an object pulled across a dry surface is determined. (2) Friction of free-falling balls in glass tubes filled with different fluids is calculated. (3) Flow resistance of a pipe from a tank is calculated. (4) Electrical resistance of a resistor is determined by use of a milliammeter and a voltmeter.

Prerequisites: 3-0.

5M1, STATIC AND SLIDING FRICTION

Resistance occurs in all energy systems. This module examines friction, the resistance in a mechanical energy system. Lubricating oils are used in automobile engines specifically to reduce friction between moving parts. At other times, it is more important to increase friction. Lining materials in automobile brakes, for example, are carefully selected to increase the friction between moving parts. In the laboratory, (1) a sliding friction block is shown to exhibit force of static and kinetic friction; and (2) friction blocks are slid on an angled surface to determine coefficient of static friction at various angles of repose.

Prerequisites: 5-0.

5M2, EFFECT OF LUBRICANTS

This module explains how lubricants overcome or reduce friction. It also lists some of the basic properties of lubricants. In the laboratory, metal blocks of various materials are slid on an aluminum plate with and without lubricants. The coefficient of static and kinetic friction is calculated for each test.

Prerequisites: 5-0.

5M3, ROLLING FRICTION

Rolling friction (the resistance to rolling movement in a mechanical system) is not as great as other friction (the resistance of sliding friction). Ball and roller bearings — both of which exhibit rolling friction in movement — have little rotational resistance. The efficiency of a mechanical system is increased when components that exhibit high sliding friction are replaced with those that exhibit rolling friction. In the laboratory, the coefficient of rolling friction is determined for a bowling ball on carpet and for a weighted bicycle wheel.

Prerequisites: 5-0.

5F1, LAMINAR AND TURBULENT FLOW

This module discusses laminar and turbulent flow and presents the Reynolds number as a ratio that describes flow quality. In the laboratory, the student will use a venturi tube, a manometer, and a needle valve to investigate laminar and turbulent flow of fluids that have different viscosities.

Prerequisites: 5-0, 3F1.

5F2, VISCOSITY

The viscosity of a liquid can be described as internal resistance to motion of the liquid. It is the primary source of resistance when a liquid flows through a pipe, when an object moves through a liquid, or when two surfaces separated by a lubricant move relative to each other. In this module the effects of viscosity in lubrication systems are presented. Methods of measuring viscosity and the effect of temperature on viscosity of lubricants also will be discussed. In the laboratory, the student will use a fashioned rolling sphere viscometer to measure the viscosity of several lubricating oils at varying temperatures.

Prerequisites: 5-0.

5F3, FLUID RESISTANCE IN PIPES

There are many causes for energy losses in any system that uses fluid power. The major cause of energy loss in a fluid-power system is friction produced when the fluid molecules bump against one another and against the pipe walls. Friction produced in this manner is manifested as heat given off to the surrounding air or to some cooling media. Heat always represents a loss of energy in a fluid-power system. In the laboratory, the student will investigate how the friction losses in a pipe are affected when the pipe's length or diameter is changed and when the viscosity of the fluid that flows through it is changed.

Prerequisites: 5-0.

5F4, VALVES AND REGULATORS

Valves are devices used to control the flow of fluids and gases. Regulators, more correctly identified as "pressure regulators," are devices that maintain a constant output pressure at different flow rates. This module discusses valves and regulators as variable fluid resistors. In the laboratory, the student will use a cylinder of nitrogen gas and a flowmeter to measure the resistance of valves and regulators.

Prerequisites: 5-0, 5F3.

5F5, SHOCK ABSORBERS

A shock absorber is a mechanical device that provides resistance in a mechanical system. In most applications, this resistance is applied to reduce mechanical oscillations. In this module, the principles of operation and the construction details of several shock absorbers are presented. In the laboratory, the student will measure resistance of an automobile shock absorber when a force is applied to it in both the compression and decompression modes.

Prerequisites: 5-0.

5F6, DRAG-RESISTANCE TO MOTION THROUGH FLUIDS

When an object moves through a fluid, or when a fluid moves around an object, a force acts to impede the motion. In this module, the properties of this fluid drag force and calculations of its magnitude are presented. Calculations for the terminal velocity of an object moving through a fluid are discussed. In the laboratory, the student will construct a device with which to measure the drag force exerted on a sphere by a regulated stream of gas and will calculate the sphere's drag resistance.

Prerequisites: 5-0, 5F1, 5F2.

5E1, OHM'S LAW

George Ohm's contribution to the mastery of electricity began with experiments concerning the relationship of the potential difference, or voltage, between the ends of a metallic conductor and the current flowing through it. What resulted is one of the most important tools for working with electricity and electronics available today. In honor of the discoverer, this tool is called "Ohm's law." This module introduces Ohm's law and its relationship to voltage, current, and resistance. In the laboratory, the student will measure and calculate these three qualities in single-resistor circuits. A d.c. power supply and a Volt-ohm-milliammeter will be used.

Prerequisites: 5-0, 3E1.

5E2, SERIES AND PARALLEL RESISTORS

Resistances connected in series form a single pathway for current flow; resistances connected in parallel form branches, each of which provides a separate path for current flow. Each type of resistance circuit has its own characteristics and uses.

Measurements and calculations often are necessary to determine if a circuit is operating as it should. In the laboratory, the student will use light bulbs as sources of resistance in place of the usual resistors, in order that the effect of series and parallel resistance circuits upon electrical current flow can be observed more directly.

Prerequisites: 5-0, 5E1.

5E3, INTERNAL RESISTANCE OF A BATTERY

Electrical applications of the resistance concept are familiar, but resistance of the power source in a circuit often is neglected, as it usually is a small value compared with the other elements in the system. In this module, applications in which the total circuit resistance is low enough to cause internal resistance of the battery to become significant are considered. In the laboratory, internal resistance of a lantern battery is calculated from measurements taken by a voltmeter through assorted resistors.

Prerequisites: 5-0.

5E4, CONDUCTORS, SEMICONDUCTORS AND INSULATORS

Whether a material is a conductor, an insulator, or a semiconductor depends upon its ability to conduct an electrical current. The conductor possesses low resistance to current flow; the insulator, high resistance; and the semiconductor, high resistance when at low temperature and low resistance at high temperature. This module examines the electrical properties of conductors, insulators, and semiconductors. In the laboratory, the student will use a VOM to determine the resistance of several material samples and will compare their characteristics.
Prerequisites: 5-0, 5E1.

5E5, RESISTANCE OF WIRES

The degree of resistance of a wire depends upon its composition, length, cross-sectional area, and temperature. A wire possessing good conductance has low resistance. A wire having strong resistance will rise in temperature and in resistance when current is increased through it. This module presents the factors affecting the resistance of wires. In the laboratory, the student will use an ammeter to determine the resistance of wires at different temperatures.
Prerequisites: 5-0, 5E1.

5E6, RESISTANCE OF SEMICONDUCTOR JUNCTIONS

Conventional resistors are "fixed" in value (except for temperature changes); therefore, their control of current flow in a circuit also is fixed. Some circuit applications, however, call for a device that has variable control over circuit current, meaning that the resistance of the device must be variable. This module examines the properties of the semiconductor P-N junction diode. The NPN transistor is analyzed to demonstrate how resistance of the output circuit is varied, or controlled, by input bias voltage. In the laboratory, the student will use a milliammeter, a micro-amp meter, and a voltmeter to measure the resistances of several diodes and transistors.
Prerequisites: 5-0, 5E1.

5E7, RESISTANCE OF GAS LASER TUBES

In this module, the electrical characteristics of the gas laser are presented. The negative resistance of the gas discharge tube is explained, and the principles of defining the general requirements for a gas-laser power supply are discussed. In the laboratory, the student will use a microammeter and a voltmeter to measure the electrical properties of a neon gas discharge tube.
Prerequisites: 5-0, 5E1.

5E8, VOLT-OHM MILLIAMMETER

Module 5-0, "Resistance," discusses the relationship of voltage, current, and resistance known as Ohm's Law. A volt-ohm-milliammeter (VOM) is a device used to measure all three of these electrical quantities. It is one of the most versatile and commonly-used test instruments in technical fields related to electrical and electronic circuits. This module deals with the basic elements of the meter and its measurement of the most common electrical quantities. Proper use and precautions to be taken with the instrument also are discussed. In the laboratory, the student will use a volt-ohm-milliammeter to measure voltage, current and resistance.
Prerequisites: 5-0.

5T1, THERMAL CONDUCTIVITY

The ability of a substance to transmit heat by conduction is a physical property of the particular materials and is characterized by its "thermal conductivity." This module investigates the heat flow rate of several materials and examines how heat flow rate varies with material, thermal conductivity, and material thickness. In the laboratory, the student will use oven thermometers, heat lamps, and a hot plate to investigate the effects of thermal conductivity and material thickness on heat flow rate.
Prerequisites: 5-0.

5T2, HEAT FLOW THROUGH INSULATION

Insulation slows down (impedes, resists) flow of heat in the same manner that a resistor impedes flow of electrical current. Increased insulation can reduce greatly the heat losses in a structure and thereby substantially reduce heating and cooling costs. In the laboratory, the student will use heat lamps and oven thermometers to determine the thermal resistance of several commercial insulating materials.
Prerequisites: 5-0, 3T2.

6-0 POWER

The concept of power has useful meaning in many energy systems. In this module, the idea of power is applied to common problems in electrical, fluid, mechanical rotational, and mechanical translational systems. Power is the rate of energy consumption and in a given energy system is the product of the forcelike quantity and rate appropriate to that system.

Laboratory Demonstrations: (1) The power developed by a person in running up stairs is calculated. (2) Calculation is made for power required to raise a weight attached by string to a rotating dowel. (3) Another experiment requires power calculations, at both input and output, of a combined electrical-fluid system (a pump); an ammeter and a voltmeter are used for measurements.
Prerequisites: 5-0.

6M1, HORSEPOWER

The origin and use of the term "horsepower" are investigated and four worked examples involving horsepower are provided. In the laboratory, the student will measure the power of an electric motor or winch in terms of its horsepower and will determine the horsepower of an automobile from its weight and acceleration.
Prerequisites: 6-0, 3M2, 3M3.

6M2, PRONY BRAKE

The prony brake is a device used to determine the operating characteristics, such as horsepower, of motors, engines, and turbines. Manufacturers often check the hp of power sources with the prony brake to ensure that the tested output power is equal to that specified. In the laboratory, the student will use a prony brake to measure speed and torque characteristics of an electric motor, will prepare a graph of speed versus torque, and will prepare a graph of motor efficiency versus torque.
Prerequisites: 6-0.

6F1, HYDRAULIC POWER

This module discusses the applications, advantages, and disadvantages of hydraulic power. Hydraulic power is produced when an incompressible fluid is pressurized by hydraulic pumps and is piped to hydraulic cylinders or motors for conversion into mechanical energy and power. In the laboratory, the student will determine the horsepower produced by a water pump sending fluid through a hydraulic system.
Prerequisites: 6-0.

6E1, ELECTRICAL POWER MEASUREMENT

Electrical power is measured to determine kWh usage and cost. In this module, the concept of electric power is reviewed, power usage is defined, and equipment for measuring watts and watthours is described. In the laboratory, the student will examine a kilowatt hour meter, use the meter to measure the power consumed by various electric appliances, and calculate an electric bill according to a typical rate structure.
Prerequisites: 6-0, 5E1.

6E2, ELECTRIC HEATER

This module presents the electric heater as an example of a purely resistive load. Calculations are provided for the determination of a heater's power consumption and its conversion of electrical energy to heat energy. In the laboratory, the student will use a voltmeter and an ammeter to determine the power consumed by an electric heater and its conversion of electrical energy to heat.
Prerequisites: 6-0.

6E3, EFFICIENCY OF ELECTRIC MOTORS AND GENERATORS

This module describes the efficiency of energy conversion in motors and generators as a ratio of output power to input power. Factors contributing to power losses and reduction of efficiency are discussed. In the laboratory, the student will use a wattmeter and a prony brake to determine the efficiency of an electric motor.
Prerequisites: 6-0.

6E4, ELECTRICAL POWER CONSUMPTION

Home appliances use varying amounts of electrical power and add varying contributions to the monthly electric bill. This module examines the relative levels of electrical power consumption for some common appliances, and discusses their costs of operation. In the laboratory, the student will measure the electrical power consumption of some appliances with a wattmeter and a kilowatt-hour meter, and will determine relative costs of operations.
Prerequisites: 6-0, 6E1.

6T1, HEAT EXCHANGERS

In this module, a heat exchanger is presented as a device that moves thermal power from one part of a thermal system to another. Solid-to-air, liquid-to-air, liquid-to-liquid, and refrigeration system exchange are described. Two working examples of power calculations are provided. In the laboratory, the student will calculate power exchange of an automobile radiator used as a heat exchanger. Equipment used includes a pump, a portable fan and a wattmeter.
Prerequisites: 6-0, 2T1.

7-0 POTENTIAL AND KINETIC ENERGY

Energy itself is a fundamental unifying concept, because it is common to all systems. In all systems we notice that whenever work is done, there is an increase in kinetic or in potential energy, or in both. When energy is transformed from one system to another, we expect the total amount of energy present to remain the same, including heat energy produced by friction. If friction is present, a portion of the work is represented by a frictional heat energy loss. In the absence of friction, the sum total of the kinetic and potential energy remains constant, although there may be exchanges between these two forms of energy. This fact, known as the "conservation of energy,"is one of the fundamental principles upon which all science and technology are based.

Laboratory Demonstrations: (1) Objects first at rest and then in rolling down an inclined track demonstrate potential energy at rest and kinetic energy in motion. (2) The exit velocity of fluid through holes in pails will be determined in two ways. (3) Mechanical energy necessary to rotate a small electric generator to charge a capacitor will be found.
Prerequisites: 6-0.

7M1, PILEDRIVER

Forging hammers and piledrivers convert gravitational potential energy to kinetic energy. In this module, the piledriver as an energy storage and delivery device is investigated. In the laboratory, the student will construct a piledriver and will investigate the effects of changes in the mass and height of the piledriver blow.
Prerequisites: 7-0, 3M3.

7M2, POTENTIAL ENERGY OF A SPRING

The stretching or compressing of a spring stores mechanical energy in the spring. This energy can be recovered as useful work by allowing the force present in the spring to cause motion toward the equilibrium position of the spring. This module discusses the forces acting upon a spring and the storage of energy in it. In the laboratory, the student will determine a spring constant and will calculate the period of a spring-mass system.
Prerequisites: 7-0.

7M3, ROTATIONAL KINETIC ENERGY OF A FLYWHEEL

A turning flywheel possesses kinetic energy in the form of the mechanical, rotational energy of its mass. This rotational kinetic energy, stored as potential energy, can be converted to other forms for use at a later time. This module provides examples of different inertia flywheels and a description of the use of a flywheel as an aid in transportation. In the laboratory, the student will construct a simple flywheel from a wheel and axle and will determine its energy-storage efficiency.
Prerequisites: 7-0.

7M4, CONSERVATION OF ENERGY IN COLLISIONS

This module discusses the conservation of momentum and kinetic energy in collisions. The ballistic pendulum is described as a device that measures the kinetic energy and momentum of a projectile in a totally inelastic collision. In the laboratory, the student will use a ballistic pendulum to determine the conservation of energy in a collision.
Prerequisites: 4-0, 7-0, 4M3.

7M5, KINETIC ENERGY AND HORSEPOWER OF AN AUTOMOBILE

In the automobile engine, chemical energy in the fuel is converted by combustion into heat energy and, in turn, into mechanical energy. Engine horsepower is the rate at which the engine can develop energy for work in propelling the automobile. This module presents a discussion of automobile engine horsepower and its measurement. In the laboratory, the student will weigh an automobile and time its acceleration on a drag strip to determine the horsepower of the engine.

Prerequisites: 3-0, 6-0, 7-0.

7F1, ENERGY STORED IN LARGE TANKS

This module presents the development of Torricelli's theorem from Bernoulli's equation. The energy exchanges that occur in the steady flow of an incompressible, viscous fluid are presented, and an application of Torricelli's theorem to the energy stored in large tanks is included. In the laboratory, the student will use an aspirator bottle or a container with a hole near the bottom to demonstrate Torricelli's theorem.

Prerequisites: 7-0.

7F2, VENTURI METERS

A venturi meter is a device used in industry for flow rate measurements. This module presents the application of Bernoulli's equation to a venturi meter and the derivation of an equation that determines flow velocity in a horizontal pipe. A discussion of potential and kinetic energy changes for fluid flowing through a horizontal pipe is included. In the laboratory, the student will use a triple-arm manometer and a venturi meter to determine velocity of flow.

Prerequisites: 7-0.

7F3, PITOT TUBES

This module presents the operating principles of the pitot tube, its advantages and limitations in fluid velocity measurement, and its various features of construction. The pitot tube equation for velocity flow is derived from Bernoulli's equation. In the laboratory, the student will use a pitot tube to measure the air speed of a moving automobile.

Prerequisites: 7-0.

7F4, ENERGY CONVERSION IN FLUID SYSTEMS

This application module demonstrates the conversion of potential energy (capacity to do work by virtue of position) into kinetic energy (capacity to do work by virtue of motion) in a fluid system. In the laboratory, the student will use a water motor equipped with a prony brake to determine the energy in a fluid system.

Prerequisites: 7-0.

7F5, GAS LAWS

Gases possess kinetic energy in the form of moving molecules that collide with each other and with objects in which they are contained. These collisions cause pressure that increases as the temperature increases. This module illustrates the solutions of many problems related to gases and introduces laws formulated to explain the behavior of gases. In the laboratory, the student will use a manometer to investigate Gay-Lussac's law and Boyle's law.

Prerequisites: 7-0, 1F1, 1F4.

7F6, SIPHONS

In this module, the physical principles that produce flow in a siphon are explained. The relationship between atmospheric pressure, liquid pressure, elevation, liquid velocity, and fluid resistance in a siphon are illustrated by the application of Bernoulli's equation. In the laboratory, the student will use containers and tubing to illustrate the relationship between fluid elevation, flow in the siphon, and fluid resistance in the siphon.

Prerequisites: 7-0, 1F1.

7E1, ENERGY STORED IN A BATTERY

This module describes the battery as a chemical energy storage device. Energy required to charge the battery is compared to energy available at discharge, and work done by the battery at various times of its discharge is discussed. In the laboratory, the student will use an ammeter and a voltmeter to measure the charging and discharging of a battery.

Prerequisites: 7-0.

7E2, ENERGY STORED IN A CAPACITOR

This module presents capacitors as devices that store electrical potential energy. Basic capacitor designs are discussed and a circuit for charging a capacitor is shown. Energy stored in a capacitor and voltage required to charge a capacitor are calculated. In the laboratory, the student will use an oscilloscope to trace the discharge of a capacitor and will calculate stored capacitor energy from his measurements.
Prerequisites: 7-0.

7E3, ENERGY STORED IN AN INDUCTOR

Magnetic potential energy is stored in the magnetic field of an inductor. In this module, air-core and iron-core inductors are contrasted, and the reaction of an inductor to changing currents is discussed in terms of the energy stored in its magnetic field. In the laboratory, the student will use an ammeter to measure the current through an automobile ignition coil and will calculate the energy stored in its magnetic field.
Prerequisites: 7-0.

7E4, SERIES AND PARALLEL CAPACITORS

This module examines the properties of circuits that include capacitors connected in series or in parallel. The concept of the potential energy of equivalent capacitance is introduced, and its practical applications are discussed. In the laboratory, the student will use a voltmeter to examine capacitors connected in series and in parallel and will determine an unknown capacitance.
Prerequisites: 7-0, 7E2.

7T1, HEAT STORAGE SYSTEMS

This module investigates the way in which various materials store heat. The heat pump is described as a mechanical device that transfers heat from one medium to another, and examples of the use of heat pumps are provided. In the laboratory, the student will compare the heat storage capacity of various materials.
Prerequisites: 7-0.

7T2, ELECTRICAL EQUIVALENT OF HEAT

In this module, the conversion of electrical potential energy to heat energy is presented. Calculations of electrical energy and heat energy are demonstrated, and their relationship is discussed. In the laboratory, the student will use a voltmeter, an ammeter, and a thermometer to investigate the conversion of electrical energy to heat.
Prerequisites: 7-0.

7T3, MECHANICAL EQUIVALENT OF HEAT

This module describes the conversion of mechanical energy to heat energy and includes examples of temperature increase in auto brakes, a waterfall, and a falling weight. In the laboratory, the student will measure the increase in temperature of falling lead balls and will calculate the mechanical equivalent of heat.
Prerequisites: 7-0.

7T4, THERMAL DRYING

In this module, the concept of kinetic energy of atoms and molecules is applied to an explanation of thermal drying of moist materials. The thermal nature of drying is explored in a discussion of molecular behavior of water vapor in accordance with the kinetic molecular theory. Evaporation of moisture from a moisture-containing solid is discussed as an important mechanism of drying. General characteristics of several types of industrial thermal dryers are presented. In the laboratory, the student will use a triple beam balance and a source of drying heat to determine the moisture content of an apple and a piece of freshly cut wood.
Prerequisites: 7-0.

7T5, MIXING LIQUIDS AT DIFFERENT TEMPERATURES

Substances possess internal kinetic energy in the form of the microscopic motion of their molecules. When liquids at different temperatures are mixed, molecular motion causes them to reach an equilibrium temperature. This module discusses the internal kinetic energy of liquids and several methods of determining specific heat and final temperature of substances mixed at different temperatures. In the laboratory, the student will construct a simple calorimeter to determine the specific heat of a liquid and the final temperature of a mixture.
Prerequisites: 7-0.

8-0 FORCE TRANSFORMERS

This module treats a class of devices called "force transformers" because, in such devices, the force output is different from the force input. However, the work, or energy output, is never greater than the work or energy, input; and with an ideal case in which no energy is lost to frictional forces, the work output equals the work input. Force transformers are simply machines having great diversity and having a wide variety of applications, but the basic explanation of their usefulness is the same. The unified approach taken in the preceding modules will assist in understanding force transformers in different energy systems as examples of the same physical principle.

Laboratory Demonstrations: (1) The mechanical advantage (M) of a lever is calculated. (2) The M of an inclined plane is found. (3) Efficiency of an electric transformer is calculated from measurements of voltage and current.

Prerequisites: 6-0.

8M1, LEVERS

In this module, the lever is presented as a force transformer. Three classes of levers are discussed, and examples and applications are presented. Equations for the calculation of actual and ideal mechanical advantage are included. In the laboratory, the student will measure and calculate the mechanical advantages of several levers.

Prerequisites: 8-0, 1M3.

8M2, WEDGES AND INCLINED PLANES

A wedge is a device that transforms a small force applied in one direction into a pair of larger opposing forces almost perpendicular to the original force. This module describes the wedge as a pair of inclined planes and provides calculations of the mechanical advantage and efficiency of a wedge. In the laboratory, the student will use spring scales to determine the mechanical advantage and efficiency of a wedge.

Prerequisites: 8-0, 1M2.

8M3, DRIVE SYSTEMS

Torque transformers called "drive systems" are employed when changes in torque and angular velocity are desired. In this module, gear systems, belt drives, and disk drives are presented as examples of torque transformers. In the laboratory, the student will examine the disk drive of a phonograph turntable.

Prerequisites: 8-0, 1M3.

8M4, GEAR TRAINS

This module discusses the design, characteristics, and applications of a variety of common gear-drive systems. Equations are presented for the calculation of the mechanical advantage, or gear ratio, of common and planetary gears. In the laboratory, the student will examine the gear train in the gear box of a machine shop lathe.

Prerequisites: 8-0, 8M3.

8M5, BLOCK AND TACKLE

This module presents the block and tackle as a pulley system that operates on the principle of lever action. Various pulley systems are discussed, and examples are provided for the calculation of mechanical advantage and efficiency. In the laboratory, the student will use a spring balance and weights to determine the mechanical advantage and efficiency of several pulley systems.

Prerequisites: 8-0.

8M6, DIFFERENTIAL HOIST

In this module, the wheel and axle are included in a block and tackle system in order to produce a differential hoist, or chain hoist. The differential hoist is described, and calculations for its mechanical advantage and efficiency are provided. In the laboratory, the student will use a spring balance and weights to determine the mechanical advantage and efficiency of a differential hoist.

Prerequisites: 8-0, 8M5.

8F1, HYDRAULIC PRESS

In this module, hydraulic force transformation, closed hydraulic systems, and mechanical advantages are presented. Pascal's law is reviewed, and practical applications to a hydraulic press are given. In the laboratory, the student will use disposable syringes, clear tubing, and weights to construct and operate a simulated hydraulic press.

Prerequisites: 8-0.

8E1, ELECTRICAL TRANSFORMERS

This module introduces the operating principles of the transformer. Voltage, current, power relationships, and transformer power losses are investigated. In the laboratory, the student will construct an electrical transformer and will use a voltmeter to measure voltage of the transformer. Calculated values of voltage will be compared to measured values.

Prerequisites: 8-0, 3E1.

9-0 ENERGY CONVERTORS

Our modern technological society depends upon the production, distribution, and consumption of large amounts of energy. These processes are made possible by a group of devices that can be classified as "energy convertors." These devices accept input energy in one energy system and deliver output energy in another system. Some of the input energy is lost, because energy convertors are not one-hundred percent efficient. This module discusses (1) a variety of energy convertors, important in the conversion and application of energy and (2) the efficiency of the individual energy convertors and systems.

Laboratory Demonstrations: (1) Efficiency of an electric water pump is determined for electrical and fluid systems. A wattmeter is employed. (2) Sunlight is converted into electrical energy by a photocell. Conversion efficiency is calculated from milliammeter measurements.

Prerequisites: 6-0.

9F1, TURBINES

In this module, the basic characteristics and operating principles of a turbine are presented. Energy transformations are traced diagrammatically for gas, steam, wind, and water turbines. In the laboratory, the student will use a prony brake to determine the efficiency of a small model water turbine.

Prerequisites: 9-0.

9F2, FLUID PUMPS

Fluid pumps convert mechanical energy into fluid energy. Fluid energy supplied by pumps is utilized either to circulate fluid or to pressurize it for use in hydraulic fluid motors or cylinders. This module discusses the principles, characteristics, and applications of the hydrodynamic pump and several types of positive displacement pumps. In the laboratory, the student will examine the characteristics of a hydrodynamic pump and will use a wattmeter to determine the power of the pump.

Prerequisites: 9-0, 6F1.

9F3, WIND POWER

Windpower is produced by machines that convert wind energy into mechanical energy, which can be used for a variety of purposes. In this module, power delivered by a windmill is discussed, and various wind-power devices and their characteristics are presented. In the laboratory, the student will use a simple wind generator to produce electricity and will use an anemometer, a voltmeter, and an ammeter to determine the conversion efficiency of wind energy into electrical energy.

Prerequisites: 9-0.

9F4, FANS AND BLOWERS

In a fan or blower, the electrical energy of the motor is converted into the rotational mechanical energy of the fan blades. The mechanical energy of the fan blades then moves the air through the discharge duct, thereby creating fluid energy. This module presents the theory of operation and basic design of fans and blowers. In the laboratory, the student will use a manometer to determine the air horsepower and the efficiency of a fan motor.

Prerequisites: 9-0.

9F5, VACUUM PUMPS

A number of different pumps are used to produce a vacuum in enclosed chambers. These pumps include rotary mechanical pumps, diffusion pumps, sputter-ion pumps, and cryogenic pumps. This module emphasizes the operation of the various types of pumps used to evacuate vacuum systems. In the laboratory, the student will use at least two different pump types to evacuate a vacuum system and will use vacuum gages to measure the pressure in the system during pump-down.
Prerequisites: 9-0, 10F5.

9E1, ELECTRIC GENERATORS

An electric generator converts rotational mechanical energy to electrical energy. This module presents the theory of operation and basic design of d.c. generators. In the laboratory, the student will operate a d.c. generator and will use a voltmeter and a milliammeter to determine the electrical power generated.
Prerequisites: 9-0, 1E4.

9E2, ALTERNATORS

In an electric generator, a voltage is produced in a conductor that moves through a magnetic field. In an alternator, the voltage is produced as the magnetic field moves through stationary coils. This module presents the theory, construction details, and applications of alternators. In the laboratory, the student will use an oscilloscope and a VOM to determine the output power and efficiency of an alternator.
Prerequisites: 9-0, 9E1.

9E3, ELECTRIC MOTORS

The electric motor converts electrical energy into mechanical rotational energy. Its operation is made possible by the magnetic field inside the motor and by the forces exerted by the field upon conductors passing through it. This module introduces the principles that govern the operation of direct current (d.c.) electric motors. In the laboratory, the student will use a horseshoe magnet and simple materials to build and operate a permanent-magnet motor and a series motor.
Prerequisites: 9-0, 1E4.

9E4, SOLENOIDS AND RELAYS

The solenoid converts electrical energy into mechanical energy. The relay contains a solenoid attached to a switch. This module discusses the operation and applications of the solenoid and the relay. In the laboratory, the student will identify relay terminals and will operate starter and electric motor control circuits.
Prerequisites: 9-0, 1E4.

9E5, PHOTOVOLTAIC MATERIALS

Photovoltaic materials are semiconductors; specifically, they are junctions between a P-type semiconductor and an N-type semiconductor. When light strikes these materials, electrical current is generated. This module examines the operation and construction of photovoltaic materials. In the laboratory, the student will use an optical power meter, a milliammeter, and a photovoltaic detector to measure efficiency of conversion of light energy into electrical energy. The light source is a Helium-neon laser.
Prerequisites: 9-0.

9T1, BOILERS

Boilers convert the thermal energy of burning fuel into the potential and kinetic energy of steam. This module discusses the energy conversion from hot combustion gases to pressurized steam in a boiler. In the laboratory, the student will determine the effects of preheated water and of ash deposits upon steam generation. A miniature steam engine is utilized.
Prerequisites: 9-0.

9T2, THERMOELECTRIC GENERATORS

This module explores thermoelectricity, the direct conversion of heat energy into electrical energy (or the reverse) by means of three related physical phenomena — the Seebeck effect, the Peltier effect, and the Thomson effect. Thermoelectric effects are exhibited by both metallic conductors and by semiconductors. In the laboratory, the student will use a potentiometer to measure the voltage generated by thermocouple wires and thermoelectric semiconductors, and will investigate cooling produced by a thermoelectric cooler.
Prerequisites: 9-0.

9T3, SOLAR COLLECTORS

This module discusses solar collectors, which convert the energy of light radiation into thermal energy or into electrical energy. Flat-plate and concentrating (focused) collectors produce thermal energy in the fluid circulating through them; whereas, photovoltaic collectors convert light radiation directly into electrical energy. In the laboratory, the student will construct a small section of a flat-plate collector and measure its efficiency, and will use a voltmeter and an ammeter to measure the conversion efficiency of a silicon photovoltaic collector.
Prerequisites: 9-0.

10-0 TRANSDUCERS

Transducers are devices that accept an input signal containing information in one energy system (engine temperature, for example) and convert it into an output signal containing the same information in another energy system (displacement of a needle on a calibrated gage scale). This module discusses transducers commonly used to transform information about mechanical, fluidal, electrical, thermal, and optical systems into an electrical or mechanical signal.

Laboratory Demonstrations: (1) A thermocouple transducer is utilized to measure water temperature. (2) Electrical energy of a horn is converted into acoustic energy through a microphone connected to an oscilloscope. (3) A turbine flowmeter is employed as a transducer to measure water flow.
Prerequisites: 9-0.

10M1, STRAIN GAGES

The strain gage is a transducer device used in the measurement of dimensional stress changes in a surface. This module introduces the construction and operation of various strain gages. In the laboratory, the student will use a Wheatstone Bridge (commercial or improvised) and a spring scale to measure the change in resistance of a wire subjected to strain, and will use a strain gage to measure strain.
Prerequisites: 10-0.

10M2, ACCELEROMETERS

In this module the piezoelectric accelerometer is presented as a device based on the principle that certain crystals exhibit surface charges when subjected to mechanical stress. Since the magnitude of the charge is proportional to the stress, these devices can be used to measure acceleration. Two types of accelerometers are described, and a working example for the calculation of acceleration is provided. In the laboratory, the student will use an accelerometer and an oscilloscope to measure a variety of accelerations.
Prerequisites: 10-0.

10F1, BOURDON TUBES

The bourdon tube is a mechanical transducer whose pressure element transforms fluid energy or motion into detectable pressure changes on a readout device. This module discusses the design and operation of the bourdon tube and describes the bellows and the diaphragm pressure transducers. In the laboratory, the student will use a regulated air pressure source, a pressure gage, and a manometer to operate and calibrate a bourdon tube.
Prerequisites: 10-0.

10F2, ANEROID BAROMETERS

An aneroid barometer is an energy transformer that accepts input energy from the pressure of a gas surrounding it and transforms it into potential energy in a spring. A pointer, or other display device, indicates the amount of energy stored in the spring. In this module, the construction and applications of an aneroid barometer are investigated. In the laboratory, the student will measure a variety of pressures with an aneroid barometer and will express each pressure in several standard pressure units.
Prerequisites: 10-0, 1F2.

10F3, DIFFERENTIAL-PRESSURE TRANSDUCERS

Differential-pressure tranducers are used when a pressure measurement involves reference to two different pressure levels. This module describes differential-pressure transducers and illustrates their use in level measurement and fluid flow measurement. In the laboratory, the student will use a regulated air supply and a manometer to investigate the operation of a differential-pressure transducer.
Prerequisites: 10-0.

10F4, FLUID-FLOW MEASURING DEVICES

This module describes the measurement of fluid flow by an orifice plate and manometer system and by a magnetic flowmeter. In the laboratory, the student will measure flow with a plate type orifice meter and with a turbine meter. Equipment used includes a pump, a mercury manometer, and a voltmeter.
Prerequisites: 10-0, 7F2.

10F5, VACUUM GAGES

This module examines a variety of different gages used to measure vacuum. Units for the measurement of pressure are discussed, and mechanical diaphragm, mercury manometers, McLeod, thermocouple, Pirani, and hot cathode ionization gages are examined. In the laboratory, the student will use a mechanical pump and valve to investigate the operation of various vacuum gages.
Prerequisites: 10-0, 9F5

10E1, METER MOVEMENTS

Meter movements are energy transducers that change part of the energy of a magnetic field into mechanical potential energy stored in a coiled spring. A pointer attached to the coil indicates the value of the current flowing through the coil. This module presents the operation and application of meter movements. In the laboratory, the student will use a commercial VOM and a meter movement to construct a voltmeter and an ammeter.
Prerequisites: 10-0, 1E3, 1E4.

10T1, AUTOMOBILE THERMOSTATS

This module presents the automobile thermostat as a device that employs the principle of thermal expansion to control the temperature of the automobile engine. As the water in the engine block is heated, thermal expansion in the thermostatic device opens a valve that allows the water to flow to the radiator. In the laboratory, the student will examine the operation of an automobile thermostat.
Prerequisites: 10-0.

10T2, BIMETALLIC STRIPS

This module discusses bimetallic strips, which are constructed of two metals that have different coefficients of linear expansion. When the strip is heated, differential expansion causes it to bend in proportion to the change in temperature. Uses of bimetallic strips as thermostats and thermometers are discussed. In the laboratory, the student will construct a bimetallic strip, measure its deflection when heated, and use a bimetallic strip to construct a control circuit.
Prerequisites: 10-0.

10T3, TEMPERATURE MEASURING DEVICES

This module presents four methods of temperature measurement: (1) fluid thermal systems (2) bimetallic strip (3) thermocouple and thermopile, and (4) thermistor. In the laboratory, the student will use a mercury thermometer, a VOM, a thermocouple, and a thermistor to measure temperature.
Prerequisites: 10-0.

10T4, THERMOCOUPLES

A thermocouple produces a thermoelectric voltage that corresponds to a temperature difference across a junction of two dissimilar metals. This module presents the theory and practical applications of thermocouples. In the laboratory, the student will use a thermometer and a voltmeter to determine the thermoelectric voltage of different thermocouples.
Prerequisites: 10-0.

10T5, THERMISTORS

The thermistor is a semiconductor transducer device whose resistance varies considerably with temperature. The resistance of some thermistors increases with a temperature increase, while that of others decreases with the same temperature increase. This module explores the construction, operation, characteristics, and applications of thermistors. In the laboratory, the student will use a VOM and a thermometer to investigate the resistance and temperature characteristics of a thermistor.
Prerequisites: 10-0.

10T6, PYROMETERS

This module describes the pyrometer as a device that measures radiation emitted from a heated material. Included are equations for the calculation of temperature from radiant power and spectral emission. Tables of emissivity of several materials are presented. In the laboratory, the student will use a radiation pyrometer and an optical pyrometer to measure the temperature of heated materials.
Prerequisites: 10-0.

11-0 VIBRATIONS AND WAVES

A wave is a periodic disturbance in either a medium, such as air, or in a vacuum, such as space. Some waves require a medium; for example, sound waves require air through which to travel. Light waves and other electromagnetic waves do not require a medium. Wave energy can be transmitted in the form of a single pulse or in many evenly-spaced pulses. Wave velocity is affected by the material through which waves travel. Two or more waves are superimposed when they overlap within the same medium to produce standing waves or interference. Wave motion applies, as a unifying concept, to mechanical, fluidal, and electrical systems.

Laboratory Demonstrations: (1) A doorbell is situated inside a bell jar in which a vacuum is created by a vacuum pump. Sound level is determined for the bell inside and outside the jar. (2) The shapes of waves in a slinky are sketched. (3) Waves are superpositioned from two loudspeakers; a microphone picks up the sounds and transmits them to an oscilloscope that displays their characteristics.

Prerequisites: 6-0.

11M1, SPEED OF SOUND IN MATERIALS

Sound waves travel through various materials with a speed dependent upon the elastic properties of the materials, characterized for each material by a constant called the "modulus of elasticity." This module discusses the velocity of sound in different types of materials. In the laboratory, the student will use an oscilloscope and a microphone to determine the velocity of sound in different media.

Prerequisites: 11-0.

11M2, REFLECTION AND ABSORPTION OF SOUND ENERGY

This module discusses sound waves, echoes, and sound absorbent materials. Absorption and reflection coefficients, sound-level measurements, and exposure to noise are examined. In the laboratory, the student will use a sound level meter or a microphone and oscilloscope to determine sound levels transmitted through, and reflected from, various materials.

Prerequisites: 11-0.

11M3, VIBRATION ISOLATION

In this module, the characteristics of steady-state vibrations are illustrated, and the methods used to eliminate or reduce these vibrations in various kinds of machinery are discussed. Equations are provided for the isolation of external and internal vibrations. In the laboratory, the student will use an oscilloscope and an accelerometer to measure the acceleration of an electric motor and its support in order to determine transmission of vibration.

Prerequisites: 11-0.

11M4, RESONANCE

Many mechanical, electrical, and fluid systems have natural frequencies at which they oscillate easily. Resonance occurs whenever pulsating energy is delivered to these systems at their natural (resonant) frequency. This module discusses resonance and gives examples of conditions in which resonance is either an advantage or a disadvantage. In the laboratory, the student will describe the resonance of four pendulums and of waves produced by tuning forks in a resonance tube.

Prerequisites: 11-0, 11E1, 11F1.

11M5, SOUND SPEAKERS

A sound speaker is a device that converts electrical energy into sound energy. In this module, the design and performance of several types of speakers is examined. Emphasis is placed on construction details of speakers that produce high fidelity sound over specific frequency ranges. In the laboratory, the student will use an audio signal generator, a microphone, an audio amplifier, and an oscilloscope to determine the frequency response of a moving coil speaker.

Prerequisites: 11-0, 1E4.

11F1, CAVITY VIBRATIONS AND STANDING WAVES

Many devices require the formation of standing waves to be able to perform their functions. Standing waves are produced when two waves of equal amplitude and frequency interfere with each other while traveling in opposite directions. A "cavity" is a volume containing a medium that supports wave reflection at the ends of the volume. This module investigates standing waves and conditions necessary for their formation. In the laboratory, the student will produce acoustic standing waves in an "organ pipe" and determine characteristics of cavity vibrations. The laboratory will require the use of an oscilloscope, an audio signal generator, a speaker, a microphone, and two tubes.

Prerequisites: 11-0.

11F2, SPEAKER ENCLOSURES

This module discusses the characteristics of bass reflex, horn, and full speaker enclosures. In the laboratory, the student will measure directionality of sound produced by a speaker with and without an enclosure. Materials to be used include an audio signal generator, an oscilloscope, a speaker, a microphone, and an audio amplifier.

Prerequisites: 11-0, 11M5, 11E3.

11F3, REVERBERATION TIME

This module describes the reverberation time of sound waves as part of the study of acoustics. The basic principles of acoustics are discussed, and an example of the calculation of reverberation time for a room is provided. In the laboratory, the student will measure the dimensions of the various surfaces in a room and will calculate the reverberation time of the room.

Prerequisites: 11-0.

11F4, DOPPLER EFFECT

The Doppler effect is the apparent change in the frequency of sound or of electromagnetic radiation due to relative motion between the source and the observer. This module examines the Doppler effect for both sound and electromagnetic waves and includes equations for the determination of frequency shifts associated with the effect. In the laboratory, the student will use a stroboscope, an oscilloscope, a microphone, and either a commercial or constructed Doppler's principle apparatus to investigate the Doppler effect of sound waves.

Prerequisites: 11-0, 11M1.

11F5, PRESSURE MEASUREMENT OF SOUND WAVES

Sound waves are small variations in pressure superimposed upon the normal atmospheric pressure. These small changes from atmospheric pressure are called "sound pressure." This module examines the elementary principles that characterize the production, transmission, and measurement of sound. In the laboratory, the student will use a sound level meter to measure sound-pressure levels and will draw the contours of equal sound-pressure levels around a sound source.

Prerequisites: 11-0.

11E1, ALTERNATING VOLTAGE AND CURRENT

When a voltage periodically changes with respect to time, it is referred to as an "alternating voltage." This alternating, wave-like voltage, when applied to a complete circuit, will cause an alternating current to flow. This module compares and contrasts a.c. and d.c. characteristics and describes the effects they produce in various circuit components, such as resistors, capacitors, and coils. In the laboratory, the student will use an oscilloscope, a signal generator, a voltmeter and an ammeter to measure peak-to-peak voltage and will compare resistance, inductive reactance, and capacitive reactance.

Prerequisites: 11-0.

11E2, PHASE RELATIONSHIPS IN a.c. CIRCUITS

Direct current encounters opposition from the resistance of conductors. Alternating current encounters both resistive opposition and opposition in the form of capacitive and inductive reactances. These reactances cause the current and voltage to be out of step with each other. This module investigates capacitive and inductive reactances, their measurements, and how they affect alternating-current circuits. In the laboratory, the student will use an ammeter and a voltmeter to determine the impedance, phase angle, and power factor of RC, RL and RLC circuits.

Prerequisites: 11-0.

11E3, OSCILLOSCOPE

The oscilloscope is one of the most important electrical devices available for measurement of electrical quantities. It is particularly useful in graphic representations of wave forms that may occur at high frequencies. This module explains the basic operation of a single-trace oscilloscope and a dual-trace oscilloscope, and it describes the use of Lissajous patterns for frequency determination. In the laboratory, the student will analyze oscilloscope sine waves, phase difference, and Lissajous patterns produced by signal generators.

Prerequisites: 11-0.

11E4, RECTIFIERS

The conversion of alternating current into direct current is necessary in many electronic circuits. A rectifier (diode) accomplishes this conversion. In this module, the principle of rectification is discussed, and the operation of a rectifier in an electrical circuit is examined. Rectification in fluid and mechanical systems also is discussed. In the laboratory, the student will assemble circuits containing rectifiers and will examine their performance with an oscilloscope.

Prerequisites: 11-0.

11E5, ELECTRONIC FILTERING IN d.c. POWER SUPPLIES

Electronic filters are used in d.c. power supplies to reduce the ripple of a.c. components at the load. Choice of the filter type to be used depends upon the ripple factor, regulation, and current of the power supply. This module discusses the construction, characteristics, and applications of several filter types. In the laboratory, the student will use electronic components, a multimeter, and an oscilloscope to construct and evaluate several filters.

Prerequisites: 11-0, 11E4.

11E6, ELECTRONIC FILTERING FOR FREQUENCY SELECTION

Electronic filtering for frequency selection is accomplished by means of reactive circuits. Reactive circuits are composed of capacitors and inductors that react to changes in the amplitude of a signal. Frequency dependence of capacitive and inductive reactance permits their use in filtering for frequency selection. This module examines high-pass, low-pass, selective, notch, band-pass, and band-stop filters. In the laboratory, the student will use a signal generator, an oscilloscope, and an ohmmeter to investigate the frequency selection of various filters.

Prerequisites: 11-0, 11E1, 11E2.

11E7, MODULATION OF ELECTRICAL WAVES

Information is transmitted through space in the form of varying electromagnetic waves. The process by which information is introduced onto a transmitted wave is called "modulation." This module discusses amplitude modulation (AM) and frequency modulation (FM), which are the two basic types of modulation used in modern communications. In the laboratory, the student will use an RF signal generator, an audio signal generator, and an oscilloscope to observe amplitude modulation of waves.

Prerequisites: 11-0.

12-0 TIME CONSTANTS

In many practical situations, it is important to know how swiftly a system will give up or accept energy, will change its temperature, or will return to equilibrium after some initial displacement. Time constants — intervals of time during which a system undergoes a change — are used to describe how fast systems are changing. If the time constant for a changing system is known, one can predict time required for the complete change to take place; for example, the time required for a capacitor to reach 99% of a fully-charged condition. In this module, time constants will be shown to be common to different energy systems and to serve, therefore, as a unifying concept.

Laboratory Demonstrations: (1) Time constants are determined for a weight attached to a flexible spring that is placed in motion. (2) A torsion pendulum flywheel is placed in motion on a shaft; the time required for it to reach a given amplitude of oscillation is calculated. (3) Water in a beaker is brought to a boil and allowed to cool to room temperature; the time constant for this process and for the thermometer used is calculated and plotted.

Prerequisites: 7-0 and a knowledge of exponential terms.

12M1, SHOCK ISOLATION BY ABSORBERS

Shock isolation in a mechanical system is accomplished by absorbers that damp mechanical oscillations transmitted from one portion of the system to another. This module examines the principles and applications of vibration isolation systems. In the laboratory, the student will use a piezoelectric accelerometer and an oscilloscope to observe vibration isolation in simple mechanical systems.
Prerequisites: 12-0, 10M2.

12F1, RATE OF EMPTYING TANKS

When large tanks are drained by gravity, the emptying process resembles the discharge of an electrical series resistance-capacitance combination and can be described by a time constant. This module describes the process of emptying a cylindrical tank and discusses the various parameters associated with the fluid flow from the tank. In the laboratory, the student will empty a large cylindrical container to demonstrate the fluid-system behavior described in the module.
Prerequisites: 12-0.

12E1, RC CIRCUITS

In electronic circuits, it often is necessary to provide some kind of timing signal to synchronize events. One of the most common sources of such a signal is a resistance-capacitance (RC) circuit. This circuit generates regularly-spaced pulses by charging and discharging a capacitor through a resistor. This module examines the characteristics of RC timing circuits and the time constant. In the laboratory, the student will construct an RC timing circuit and test it with an oscilloscope.
Prerequisites: 12-0.

12E2, RL CIRCUITS

An RL series circuit consists of resistance R in series with an inductor of self-inductance L. To distinguish between the effects of resistance and self-inductance, the RL circuit analyzed in this module consists of an ideal, resistanceless inductor in series with a separate noninductive resistor. An example of a real inductor with resistance is included. In the laboratory, the student will use an oscilloscope, a signal generator, and a VOM to determine the exponential behavior of current and voltage, and will measure the time constant associated with their decay.
Prerequisites: 12-0, 11E2, 7E3.

12E3, RLC CIRCUITS

This module examines the characteristics and applications of resistance-inductance-capacitance (RLC) circuits. Examples of RLC circuit problems are presented, and an equation for the calculation of energy stored in a capacitor is included. In the laboratory, the student will use an oscilloscope, a VOM, and several circuit components to observe the pulse shapes of overdamped, underdamped, and critically damped RLC circuits.
Prerequisites: 12-0, 12E1.

12T1, RESPONSE TIME OF THERMOCOUPLES

This module discusses heat in situations in which temperature is changing rapidly. Under these conditions, response time of a temperature-measuring device becomes important. Response time of a thermocouple depends upon its size, its material, and its bonding to the material under study. In the laboratory, the student will use an oscilloscope and liquid nitrogen or ice-water to determine response times for a conventional thermocouple and a thin-film thermocouple, and will use a thermocouple attached to a strip chart recorder to measure thermal diffuseness of a sample of metal.
Prerequisites: 12-0.

12T2, TIME CONSTANTS OF HEATING AND COOLING

Time constants associated with the response of temperature-measuring devices are important factors to consider in the design of an accurate temperature-measuring system. This module describes time constants for heating and cooling and relates the time constants to the rate of temperature changes of a body as it heats or cools. In the laboratory, the student will use thermometers and insulated containers to determine how different surface characteristics of a hot body affect the time constant and the rate at which it cools.
Prerequisites: 12-0.

13-0 RADIATION

Radiation is the process by which energy moves away from a source in a straight line. Sound waves, light waves, and alpha and beta rays are examples of radiation. Although these examples represent three distinct classes of radiation, each example moves energy radially away from some source, and all have common characteristics.

This module addresses mainly the topic of electromagnetic (EM) radiation — sometimes called "radiant energy." In this type of radiation, energy is transmitted by variations in electric and magnetic fields. Radiant energy includes gamma rays, x-rays, ultraviolet, visible, infrared, microwaves, radar, television, and radio waves. It is the basis of modern communication, of solar energy, and of sight itself.

Laboratory Demonstrations: (1) The laws of reflection and refraction are demonstrated with a He-Ne laser. (2) Polarized EM radiation is emitted by a microwave transmitter through a grid analyzer to a receiver. (3) The inverse-square law is demonstrated by use of a light bulb and a light meter.
Prerequisites: 11-0, 1E3, 1E4.

13L1, INVERSE SQUARE LAW — SPREADING OF LIGHT

This module presents the inverse-square law, which describes the rate of decrease in irradiance of light as the distance from its source increases. The concepts of solid angle, radiant intensity, and irradiance are explained and calculated in examples. In the laboratory, the student will use an incandescent bulb and an optical power meter to measure irradiance as a function of distance from a light source.
Prerequisites: 13-0.

13L2, THE OPTICAL SPECTRUM

This module presents the characteristics and applications of light within the optical spectrum, which includes the infrared, visible, and ultraviolet portions of electromagnetic spectrum. Common wavelength units and the origin of continuous, band, and line spectra are discussed. Equations for calculating the frequency and energy of a photon are presented and used in examples. In the laboratory, the student will use a grating spectroscope to measure the wavelength of visible light from various sources, and will calculate the frequency and energy of photons.
Prerequisites: 13-0.

13L3, LIGHT SOURCES

In this module, the process by which light is produced in incandescent, fluorescent, and metal vapor light sources is presented. The discussion includes characteristics of point and extended sources of light. In the laboratory, the student will use an optical power meter and a grating spectroscope to observe the irradiance pattern and output spectra of incandescent and fluorescent sources.
Prerequisites: 13-0, 13L1, 13L2.

13L4, LASERS

The laser is a source of unique light radiation and has a wide variety of applications. Laser light is used to drill holes in diamonds, to weld steel accurately, to measure large distances, and to repair detached retinas. This module discusses the properties of laser light, the basic theory of operation of the laser, and a number of important laser applications. In the laboratory, the student will learn how to operate a low-power, helium-neon laser.
Prerequisites: 13-0.

13L5, STROBOSCOPES — PULSES OF LIGHT

In this module, the stroboscope is presented as a device that produces short pulses of light. The major parts of a stroboscope and of an automobile engine timing light are described. In the laboratory, the student will use a stroboscope to measure the rotational rate of a fan and to observe water drop formation and will utilize an automobile timing light (strobe-light) to check the timing of an automobile engine.
Prerequisites: 13-0.

13L6, OPTICAL FILTERS — ABSORPTION OF LIGHT

This module presents the absorption of light by atoms, the exponential law of absorption, and the transmission curves for several types of optical filters. The absorption coefficient of a filter material is defined and used in examples. In the laboratory, the student will use a laser and an optical power meter to derive curves of transmission versus filter thickness and to calculate the absorption coefficient of optical filters.
Prerequisites: 13-0, S3, 13L2, 13L3.

13L7, SPECULAR AND DIFFUSE REFLECTION OF LIGHT

This module discusses the law of reflection as it applies to specular and diffuse reflectors. Absorption, scattering, reflection, and transmission at optical surfaces are presented. Applications of partial and total reflectors are discussed. In the laboratory, the student will use a helium-neon laser and a power meter to compare the characteristics of diffuse and specular reflections.

Prerequisites: 13-0, 13L4.

13L8, IMAGE FORMATION WITH MIRRORS

This module presents the formation of images by mirrors. Ray diagrams are included to illustrate the formation of virtual and real images by plane and spherical mirrors. Equations for determining image location and size are provided, and applications of several optical arrangements employing mirrors are presented. In the laboratory, the student will use a concave mirror to construct a solar furnace and to create real and virtual images.

Prerequisites: 13-0, 13L7.

13L9, PRISMS – REFRACTION AND DISPERSION OF LIGHT

Reduction of the speed of light as it passes through a prism is responsible for light refraction (bending) and for light dispersion (spreading of colors). This module presents refraction of light at plane surfaces and a discussion of variations in the angle of refraction for different colors of light. In the laboratory, the student will use a prism spectrometer to measure light velocity and index of refraction of a prism at several wavelengths of light.

Prerequisites: 13-0, 13L2.

13L10, LENSES – FOCUSING AND SPREADING OF LIGHT

Lenses are optical devices that change the directionality of light beams by refracting different parts of the beams by differing amounts. This module discusses properties of lenses, formation of real and virtual images by lenses, and a variety of lens applications. In the laboratory, the student will use lenses to construct a small refracting telescope.

Prerequisites: 13-0, 13L9.

13L11, INTERFERENCE – TESTING FLAT SURFACES

This module describes interference as the way in which light waves interact. If two light waves are in phase at a point on a screen, a bright spot is produced. If the two waves are completely out of phase, a dark area results. The alternating light and dark fringes of such an interference pattern can provide useful information about the surface dimensions of an object. In the laboratory, the student will use a mercury vapor lamp, an optical flat, and a positive lens to investigate interference patterns.

Prerequisites: 13-0, 13L1, 13L7.

13L12, DIFFRACTION GRATING – MEASURING THE WAVELENGTHS OF LIGHT

This module discusses Huygens' principle and the diffraction of light at edges and slits. Equations are presented for the calculation of wavelength, diffraction angle, and grating spacing. In the laboratory, the student will use a grating spectroscope to measure the wavelength produced by a helium spectrum tube.

Prerequisites: 13-0, 13L2, 13L9, 13L11.

13L13, POLARIZATION – GLARE REDUCTION

The polarization of light is a description of the orientation of its electric field in space. This module discusses characteristics of polarized light and methods of producing and measuring polarization of light. The origin of glare and its reduction by polarizing optical components also is presented. In the laboratory, the student will use a helium-neon laser, an optical power meter, and two linear polarizers to investigate the polarization of coherent light.

Prerequisites: 13-0, 13L4.

13L14, HOLOGRAPHY – THREE DIMENSIONAL PHOTOGRAPHY

Holography is a method of using coherent laser light to record and reproduce three-dimensional images. This module discusses the differences between holography and ordinary photography, techniques used in making and viewing holographic images, and several applications of holography. In the laboratory, the student will use a helium-neon laser, a diverging lens, and a hologram to observe the three-dimensional image produced by holography.

Prerequisites: 13-0, 13L4, 13L12.

13L15, SPECTROSCOPY – LIGHT ANALYSIS

Spectroscopy is an analysis of light emitted by, reflected from, or transmitted through a material and may be used to determine a variety of things about the material. This module discusses several types of optical instruments used in spectroscopy and presents a wide variety of applications of spectroscopy in science and industry. In the laboratory, the student will use a spectrophotometer to determine the transmission curve of a didymium filter.

Prerequisites: 13-0, 13L2, 13L6, 13L8, 13L11, 13L12.

13L16, INFRARED RADIATION THERMOMETERS

This module discusses the way in which the infrared radiation emitted from most objects can be used to determine the object's temperature. The design and limitations of a simple infrared radiation thermometer are presented. In the laboratory, the student will make practical measurements with an infrared radiation thermometer.

Prerequisites: 13-0, 13L2.

13L17, ILLUMINATION

This module examines different quantities associated with the measurement of radiant energy. The efficiency and spectral composition of various light sources are presented. The principles of operation and practical applications of light-measuring devices are examined, and minimum lighting requirements for various activities are discussed. In the laboratory, the student will use a photoelectric light meter to measure the illumination of several rooms.

Prerequisites: 13-0, 13L1, 13L2, 13L3.

13L18, SINGLE LENS REFLEX CAMERA

A single lens reflex camera (SLR) allows the photographer to view a scene, to focus, and to measure light intensity through the same lens used in taking photographs. This module introduces the optics, shutter speed, f-stop (lens opening), metering, film, viewing, and focusing of the SLR camera. In the laboratory, the student will use a convex lens, a Fresnel field lens, a pentaroof prism, and a Polaroid camera to determine image characteristics and depth of focus.

Prerequisites: 13-0, 13L1, 13L9, 13L10.

13N1, GEIGER COUNTERS

This module presents the Geiger counter as an instrument used in the detection and measurement of radiation. The Geiger-Müeller detector is a gas-filled tube that detects radioactive particles, which ionize the atoms of the gas. This ionization produces electrical pulses that register the intensity of radiation. In the laboratory, the student will use an electronic scaler to determine the operating voltage of a Geiger counter, and will measure ionizing radiation produced by a radioactive source.

Prerequisites: 13-0.

13N2, PENETRATING POWER OF ALPHA AND BETA RADIATION

Alpha and beta particles lose energy as they pass through a material because they collide with the electrons in the material and give up energy to them. The distance the particle is able to travel in the material is its "range." This module describes the range of a particle as a function of its energy. In the laboratory, the student will use a Geiger counter to determine the range of alpha and beta particles in metal foils.

Prerequisites: 13-0, 13N4, 13N1.

13N3, RADIOACTIVITY

This module explores radioactivity, the emission of radiation during the decay of the unstable nuclei of atoms. Three different types of radiation, denoted as "alpha," "beta," and "gamma," are produced. Radioactive atoms decay over a period of time and are characterized by a "half-life." For different radioisotopes, half-lives vary from a fraction of a second up to billions of years. In the laboratory, the student will use a Geiger counter to measure the decay rate and source strength of a radioactive source, and will verify the inverse square-law dependence of the counting rate on distance from the source.

Prerequisites: 13-0, 13N4, 13N2, 13N1.

13N4, ABSORPTION OF GAMMA RADIATION

This module discusses the absorption of gamma radiation, which is an electromagnetic radiation that has a wavelength shorter than that of light. The absorption of gamma radiation is described by the same type of exponential equation that characterizes the absorption of light. The absorption coefficient for gamma radiation in a material depends upon the wavelength of the radiation and upon the properties of the absorbing material. In the laboratory, the student will use a Geiger counter to measure the transmission of gamma radiation through lead and aluminum, and will use the results to calculate absorption coefficients for these two materials.

Prerequisites: 13-0, 13N1.

APPENDIX D

SOLUTIONS TO MODULE SELF-CHECK PROBLEMS

S1. FORMULA INTERPRETATION

(a) $V = IR$

$R = \frac{V}{I}$

(b) $a = \frac{v_2 - v_1}{t} = \frac{v_2}{t} - \frac{v_1}{t}$

$v_2 = at + v_1$

(c) $V^2 = V_\sigma^2 + 2as$

$s = \frac{V^2 - V_\sigma^2}{2a}$

(d) $T = \sqrt{2\,h/g}$; $T^2 = 2\,h/g$

$h = \frac{T^2 g}{2}$

(e) $(m - ut)\,a = uv$

$m = \frac{uv}{a} + ut$

(f) $E_K = \frac{1}{2}\,mV^2$

$V = \frac{2E_K}{m}$

(g) $E_K = \frac{1}{2}\,mV^2 + \frac{1}{2}\,I\omega^2$

$V = \sqrt{\frac{2E_K - I\omega^2}{m}}$

(h) $w^2 = \frac{2\,\mu h}{mr^2 + J}$; $(mr^2 + J)w^2 = 2\,\mu h$

$r = \sqrt{\frac{2\,\mu h}{mw^2} - \frac{J}{m}} = \sqrt{\frac{2\,\mu h - w^2 J}{mw^2}}$

S2, INTERNATIONAL SYSTEM OF UNITS

5. 4876000 Ω = 4.876 MΩ

0.0027 cm = 27 μm

1440 mW = 1.44 W

5.2×10^4 g = 52 kg

0.055 ms = 55 μs

6. $15 \text{ m/s} \div 8 \text{ s} = 1.875 \text{ m/s}^2$

$650 \text{ kg} \times 3.2 \text{ m/s} = 2080 \text{ kg·m/s} = 2.080 \text{ kN/s}$

$0.28 \text{ kg} \div 30 \text{ x} = 9.33 \times 10^{-3} \text{ kg/x} = 9.33 \text{ g/x}$

8. $16 \text{ ft} \left(\frac{12 \text{ in}}{\text{ft}}\right)\left(\frac{2.54 \text{ cm}}{1 \text{ in}}\right) = 487.68 \text{ cm} = 4.8768 \text{ m}$

$(27.5 \text{ in})(2.54 \text{ cm/in}) = 69.85 \text{ cm}$

$(0.025 \text{ in})(2.54 \text{ cm/in}) = 0.0635 \text{ cm} = 0.635 \text{ mm}$

9. $(15 \text{ kg})(2.2 \text{ lb/kg}) = 33 \text{ lb}$

$(350 \text{ g})\left(\frac{1 \text{ kg}}{1000 \text{ g}}\right)\left(\frac{2.2 \text{ lb}}{\text{kg}}\right) = 0.77 \text{ lb}$

S3, LOGARITHMS AND EXPONENTS

1. (a) 2.93×10^{3}
   (b) 2.62×10^{5}
   (c) 7.04×10^{2}
   (d) 7.13×10^{-2}
   (e) 1.95×10^{-1}
   (f) 8.33×10^{-9}

2. (a) 6.6152×10^{4}
   (b) 2.8136×10^{-4}
   (c) -3.749×10^{4}
   (d) 5.44×10^{-7}
   (e) 2.0×10^{1}
   (f) 2.56×10^{11}

3. (a) 2.7033
   (b) -3.0
   (c) 2.9675
   (d) 2.6358
   (e) -0.5108
   (f) 3.5351

4. (a) 6.62×10^{3}

(b) 1.6×10^{-3}

(c) 2.79×10^{5}

(d) 3.17×10^{3}

5. $R = 10^{6} \left(\frac{t}{c}\right) \left[\frac{1}{\ell n \left(\frac{V_o}{V}\right)}\right]$

$= 10^{6}\left(\frac{120}{0.082}\right) \left[\frac{1}{\ell n \left(\frac{123}{115.8}\right)}\right]$

$R = 2.43 \times 10^{10}$

6. $i = I \left(1 - e^{-\frac{Rt}{L}}\right)$

$= 100 \left[1 - e^{-\left(\frac{16 \cdot 0.02}{0.80}\right)}\right]$

$i = 3.30 \times 10^{1}$

7. $V = E\, e^{-\frac{t}{RL}}$

$\ell n \frac{V}{E} = -\frac{t}{Rc}$; $-Rc\ \ell n \left(\frac{V}{E}\right) = t$

$t = Rc\ \ell n \left(\frac{E}{V}\right) = (12)(0.05)\ \ell n \left(\frac{200}{49}\right) = 8.44 \times 10^{-1}$

8. $W = p_o\, V_o\, \ell n \left(\frac{V_1}{V_o}\right)$

$\frac{W}{p_o V_o} = \ell n \frac{V_1}{V_o}$

$e^{\frac{W}{p_o V_o}} = \frac{V_1}{V_o}$; $V_1 = V_o\, e^{\frac{W}{p_o V_o}}$

S4, ANGLES AND TRIANGLES

5. $A^2 + B^2 = C^2$

$(17 \text{ miles})^2 + (15 \text{ miles})^2 = C^2 = 514 \text{ miles}^2$

$C = 22.67 \text{ miles}$

6. $\tan \theta = \frac{\text{Length of opp. side}}{\text{Length of adj. side}} = \frac{h - 5 \text{ ft}}{30 \text{ ft}}$

$\tan 30° = 0.577 = \frac{h - 5 \text{ ft}}{30 \text{ ft}}$, $h - 5 \text{ ft} = 17.32 \text{ ft}$

$h = 22.32 \text{ ft}$

7. (a) D_n = (5 miles) sin 20° = 1.71 miles

D_W = (5 miles) cos 20° = 4.70 miles

(b) F_V = (10 lb) sin 45° = 7.07 lb

F_H = (10 lb) cos 45° = 7.07 lb

(c) F_x = (60 N) sin 35° = 34.41 N

F_y = (60 N) cos 35° = 49.15 N

S5, VECTORS AND SCALARS

6. 129.97 miles 264° east of north

S6, DIMENSIONAL ANALYSIS

2. (a) $\frac{\text{lb s}^2}{\text{ft}}$

(b) $\text{kg}\cdot\text{m/s}^2$

(c) $\text{kg}\cdot\text{m}^2/\text{s}^2$

(d) $\text{kg}\cdot\text{m}^2/\text{s}^3$

(e) $\text{kg}\cdot\text{m}^2/\text{s}^2$

3. $F = \frac{1}{2} kx^2$

units of F = $(\text{kg/m}\cdot\text{s}^2)\ \text{m}^2 = \text{kg}\cdot\text{m/s}^2 = \text{N}$

4. $\rho_m = \frac{m}{\pi r^2 h}$

$\rho_m = \frac{0.360\ \text{kg}}{\pi(0.03\ \text{m})^2(0.1\ \text{m})} = 1.27 \times 10^3\ \text{kg/m}^3$

5. $1\Omega = 1\ \text{V/A} = \frac{1\ \text{J/C}}{1\ \text{C/s}} = (1\ \text{J/C})(1\ \text{s/C}) = 1\ \text{J}\cdot\text{s/C}^2$

6. (a) 1

(b) 2

(c) None of the above - correct answer is 5.3×10^5 min.

(d) 2

(e) 1

S7, READING AND DRAWING GRAPHS

No calculations required.

S8, PRECISION, ACCURACY, AND MEASUREMENT

4. Average = 1.28 cm

$$\text{S.L.E.} = \frac{4\,(\text{a.d.})}{\sqrt{n}} = \frac{4\,(0.0067)\ \text{cm}}{\sqrt{9}} = 0.0089\ \text{cm}$$

I.L.E. = 0.005 cm

L.E. = I.L.E. + S.L.E. = 0.014 cm

5. $V = (\frac{4}{3})\,\pi r^3$

$$V = \frac{4}{3}\,(\pi)(\frac{1.28\ \text{cm}}{2})^3 = 1.10\ \text{cm}^3$$

$$r = \frac{1.28 \pm 0.014\ \text{cm}}{2} = 0.64 \pm 0.007\ \text{cm} = 0.64 \pm 1.1\%$$

$V = 1.10\ \text{cm}^3 \pm 3(1.1\%) = 1.10\ \text{cm}^3 \pm 3.3\% = 1.10\ \text{cm}^3 \pm 0.036\ \text{cm}^3$

1-0, FORCE

2. $F_T = F_1 + F_2 + F_3$; Let right be the positive direction.

$F_T = 40$ lb - 180 lb + 200 lb

$F_T = 60$ lb (to the right)

3. $F_{xT} = F_{x_1} + F_{x_2} + F_{x_3}$; $F_{yT} = F_{y_1} + F_{y_2}$; Let x be horizontal and y be vertical. Let right and up be the positive direction.

$F_{xT} = -30$ N + 10 N + 20 N = 0 ; No resultant force in x direction

$F_{yT} = F_T = 8$ N - 12 N = -4 N (down)

4. $\tau = F\ell$ so $\ell = \frac{\tau}{F}$

$$\ell = \frac{32.8\ \text{ft}\cdot\text{lb}}{10\ \text{lb}}$$

$\ell = 3.28$ ft

5. 1 lb = 4.45 N ; 1 m = 3.28 ft ; $\ell = \frac{\tau}{F}$

$$\ell = \frac{(3.28\ \text{ft}\cdot\text{lb})\,(\frac{1\ \text{m}}{3.28\ \text{ft}})(\frac{4.45\ \text{N}}{\text{lb}})}{(10\ \text{lb})(\frac{4.45\ \text{N}}{\text{lb}})}$$

$\ell = 1$ m ; This agrees with the answer to problem 4.

6. $\tau = F\ell$, $\tau_T = \tau_1 + \tau_2 + \tau_3$, Let clockwise be the positive direction; $W = mg$

$\tau_T = -(4\text{ kg})(9.8\text{ m/s}^2)(0.4\text{ m}) + 2\text{ kg}\ (9.8\text{ m/s}^2)(0.2\text{ m}) + 4\text{ kg}\ (9.8\text{ m/s}^2)(0.3\text{ m})$

$\tau_T = 0$ (The meter stick does not rotate.)

7. $p = \frac{F}{A}$

$= \frac{130\text{ lb}}{(0.5\text{ in})^2}$

$p = 520\text{ lb/in}^2$

8. $p = \rho_w h$; $1\text{ ft}^2 = 144\text{ in}^2$

$p = (62.4\text{ lb/ft}^3)(250\text{ ft})$

$p = (15{,}600\ \frac{\text{lb}}{\text{ft}^2})(\frac{1\text{ ft}^2}{144\text{ in}^2}) = 108.3\text{ lb/in}^2$

9. $p = \rho g h \therefore h = \frac{p}{\rho g}$

$h = \frac{10^5\text{ n/m}^2}{(1000\text{ kg/m}^3)(9.8\text{ m/s}^2)}$

$h = 10.2\text{ m}$

10. $V_{AB} = V_1 + V_2 + V_3$

(a) $V_{AB} = 6V + 3V + 1.5\text{ V} = 10.5\text{ V}$

(b) $V_{AB} = 6V - 3V + 1.5\text{ V} = 4.5\text{ V}$

11. $T°C = 5/9\ (T°F - 32°F)$

(a) $T°C = 5/9\ (413°F - 32°F) = 211.7°C$

(b) $T°C = 5/9\ (26°F - 32°F) = -3.3°C$

(c) $T°C = 5/9\ (-13°F - 32°F) = -25°C$

12. $T°F = 32°F + 9/5\ T°C$

(a) $T°F = 32°F + 9/5\ (25.2°C) = 77.9°F$

(b) $T°F = 32°F + 9/5\ (5°C) = 41°F$

(c) $T°F = 32°F + 9/5(-40°C) = -40°F$

1M1, GRAVITY

3. $F = \frac{Gm_E m_M}{(r)^2}$, $m_E = 5.98 \times 10^{24}$ kg

$$= \frac{(6.67 \times 10^{-11}\ N \cdot m^2/kg^2)(5.98 \times 10^{24}\ kg)(7.34 \times 10^{22}\ kg)}{(3.86 \times 10^{8}\ m)^2}$$

$F = 1.965 \times 10^{20}$ N

5. $v = at$

$v = (9.8\ m/s^2)(10\ s)$

$v = 98$ m/s

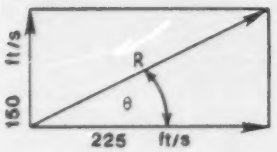
6. $F = ma$, $m = \frac{F}{a}$

$m = \frac{100\ N}{5\ m/s^2} = \frac{160\ N}{8\ m/s^2}$

$m = 20$ kg

1M2, ADDITION OF MECHANICAL FORCES

2. (a)

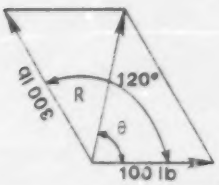


$R = \sqrt{x^2 + y^2} = \sqrt{(225\ ft/s)^2 + (150\ ft/s)^2} = 270$ ft/s

$\cos\theta = \frac{225\ ft/s}{270\ ft/s} = .833$

$\theta = 33.6°$ ∴ R = 270 ft/s, 33.6°

(b)



$\Sigma X = 100\ lb + (-300\ lb \sin 30°) = -50\ lb$

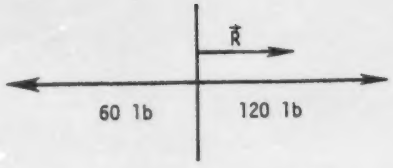
$\Sigma Y = 300 \cos 30° = 260\ lb$

$R^2 = \sqrt{X^2 + Y^2} = \sqrt{(-50\ lb)^2 + (260\ lb)^2} = 265$ lb

$G = \cos^{-1}\left(\frac{-50\ lb}{265\ lb}\right) = 101°$

∴ R = 265 lb, 101°

(c)



R = 60 lb, to the right

(d) $\Sigma X = 20$ N; $\Sigma Y = -64$ N

$R = \sqrt{X^2 + Y^2} = 67$ N

$\theta = \sin^{-1}\left(\frac{-64\ N}{67\ N}\right) = -72.6°$ $\therefore$ R = 67 N, -72.6°

(e) $\Sigma X = 13.1$ ft; $\Sigma Y = 27.2$ ft

$R = \sqrt{X^2 + Y^2} = 30.2$ ft

$\theta = \cos^{-1}\left(\frac{13.1\ ft}{30.2\ ft}\right) = 64.3°$

R = 30.2 ft, 64.3°

(f) $\Sigma X = 5.7$ N; $\Sigma Y = 7.9$ N

$R = \sqrt{X^2 + Y^2} = 9.7$ N

$\theta = \sin^{-1}\left(\frac{7.9\ N}{9.7\ N}\right) = 54.5°$

R = 9.7 N, 54.5°

1M3, ADDITION OF TORQUES

3. (a) $\Sigma\tau = \vec{0}$

$0 = (100\ g)(10\ cm) + 50\ g\ (40 - X_2)\ cm - 162\ (10\ cm)$

$X_2 = 27.6$ cm

(b) $\Sigma\tau = \vec{0}$

$0 = m_2\ (30\ cm) - 162\ g\ (10\ cm)$

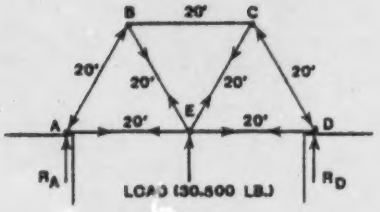
$m_2 = 54$ g

(c) $\Sigma\tau = 0$

$0 = 100\ g\ (30\ cm) - 362\ g\ (10\ cm) + 50\ g\ (40 - X_3)\ cm$

$X_3 = 27.6$ cm

2.



For example, STRUT AB is under tension while STRUTS AE and BE are under compression

3. $\Sigma F = 0$, $\Sigma \tau = 0$

$\Sigma F = -1000$ lb + 250 lb + 500 sin 25° + $F_1 = 0$

$F_1 = 539$ lb (directed upward)

To find the position of the center of mass, one must apply the second equilibrium condition. Let the pivot be the point at which the board is fastened to the support, and let the counter-clockwise direction be positive.

$\Sigma \tau = 1000$ lb(x) - 250 lb (4 ft) - 539 lb (10 ft) - 500 sin 25° (10 ft) = 0

x = 8.5 ft

4. Refer to figure in problem 2 above:

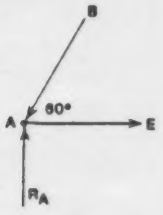
$R_A = R_D$ (by symmetry) ; $R_A + R_D = 30,500$ lb, 50

$R_A = R_D = 15,250$ lb

$\Sigma F_V = 0$; $\Sigma F_H = 0$ (at each junction)

Let upward and right be the positive directions.

at junction A.



$\Sigma F_V = R_A + F_{AB} \sin 60° = 0$

$F_{AB} = \frac{-15,250 \text{ lb}}{\sin 60°} = -17,610$ lb toward junction A

$\Sigma F_H = F_{AB} \cos 60° + F_{AE} = 0$

$F_{AE} = (17,610 \text{ lb})(\cos 60°) = 8805$ lb away from junction A

at junction B.

$\Sigma F_V = F_{AB} \sin 60° + F_{BE} \sin 60° = 0$

$F_{BE} = -F_{AB} = -17{,}610$ lb away from junction B

$\Sigma F_H = F_{AB} \cos 60° + F_{BE} \cos 60° + F_{BC} = 0$

$17{,}610 \cos 60° - 17{,}610 \cos 60° + F_{BC} = 0$

$F_{BC} = 0$

Since the structure is symmetrical,

$F_{AB} = F_{DC} = 17{,}610$ lb under tension

$F_{AE} = F_{DE} = 8{,}805$ lb under compression

$F_{BE} = F_{CE} = 17{,}610$ lb under compression

$F_{BC} = 0$

See drawing in problem 2 for directions of each force.

1M5, STRESS AND STRAIN

2. $S = \frac{F}{A}$

$= \frac{3000 \text{ lb}}{8 \text{ in}^2}$

$S = 375 \text{ lb/in}^2$

3. $e_\ell = \frac{\Delta \ell}{\ell_o}$

$= \frac{5.73 \text{ in} - 6 \text{ in}}{6 \text{ in}}$

$e_\ell = -0.045$

4. $E = \frac{\text{stress}}{\text{strain}}$

$= \frac{1500 \text{ lb/in}^2}{0.125}$

$E = 12{,}000 \text{ lb/in}^2$

3. $\Sigma F_V = 0$; $\Sigma F_H = 0$;

$\Sigma F_V = 0 = T_L \sin 60° + T_R \sin 45° - 10{,}000$ lb

$\Sigma F_H = 0 = T_R \cos 45° - T_L \cos 60°$

$$T_R = \frac{T_L \cos 60°}{\cos 45°} = T_L\,(0.707)$$

Substituting this expression for T_R into the equation of the vertical components yields

$T_L\,(0.866) + T_L\,(0.707)(0.707) - 10{,}000$ lb $= 0$

$T_L = 7321$ lb; $T_R = T_L\,(0.707) = 5176$ lb

4. $\Sigma F_V = 0$; $\Sigma F_H = 0$; T_C is the tension in the cable; F_S is the force due to the strut.

$$\tan \angle CAB = \frac{20 \text{ ft}}{11.5 \text{ ft}} = 1.74; \quad \angle CAB = 60.1°$$

$\tan \angle ABC = 1$; $\angle ABC = 45°$

$\Sigma F_V = -2000$ lb $+ T_C \cos 60.1° + F_S \cos 45° = 0$

$\Sigma F_H = T_C \sin 60.1° - F_S \sin 45° = 0$

$$F_S = \frac{T_C\,(\sin 60.1°)}{\sin 45°} = (1.23)\,T_C$$

$\Sigma F_V = 0 = 2000$ lb $- T_C\,(0.5) - T_C\,(1.23)(0.707)$

$T_C = 1460$ lb

5. $\Sigma F_V = 0$; $\Sigma F_H = 0$, Let T_R be the tension in the rope and F_S be the force due to the support.

$$\angle \text{ at winch} = \tan^{-1}\left(\frac{20 \text{ ft}}{40 \text{ ft}}\right) = 26.6°$$

$$\angle \text{ at pt. A} = \tan^{-1}\left(\frac{20 \text{ ft}}{20 \text{ ft}}\right) = 45°$$

$\Sigma F_V = -1000$ lb $+ T_R\,(\sin 26.6°) + F_S\,(\cos 45°) = 0$

$\Sigma F_H = F_S\,(\sin 45°) - T_R\,(\cos 26.6°) = 0$

$$F_S = \frac{T_R\,(\cos 26.6°)}{\sin 45°} = (1.26)\,T_R$$

$\Sigma F_V = -1000$ lb $+ T_R\,(\sin 26.6°) + (1.26)\,T_R\,(\cos 45°) = 0$

$T_R = 747$ lb

6. $$T_{max} = \frac{W\ell}{2}\sqrt{\frac{\ell^2}{16\,s^2} + 1}$$

$$= \frac{(0.4 \text{ lb/ft})(200 \text{ ft})}{2}\left(\sqrt{\frac{(200 \text{ ft})^2}{16\,(10 \text{ ft})^2} + 1}\right)$$

$T_{max} = 204$ lb

7. $H = \frac{W\ell^2}{8\,s}$, where H is the weight required for a serg of 2 feet.

$$= \frac{(0.05\ \text{lb/ft})(80\ \text{ft})^2}{8\ (2\ \text{ft})}$$

$H = 20$ lb

1F1, ATMOSPHERIC PRESSURE

5. $p_1V_1 = p_2V_2$; $V_1 = \frac{p_2V_2}{p_1}$

$$V_1 = \frac{(2000\ \text{lb/in}^2)(2.5\ \text{ft}^3)}{(14.7\ \text{lb/in}^2)}$$

$V_1 = 340\ \text{ft}^3$

1F2, DENSITY, BUOYANCY, AND SPECIFIC GRAVITY

3. Yes, if the object raised has sufficient volume to displace at least 2 lbs of water.

4. Yes; S.G. = $\frac{\text{weight of material}}{\text{weight of equal volume of water}}$

5. $S.G._{Al} = \frac{\rho_{Al}}{\rho_w} = \frac{W_{Al}/V_{Al}}{\rho_w}$; $W_{Al} = (S.G._{Al})(\rho_w)(V_{Al})$

$$W_{Al} = (2.7)(62.4\ \text{lb/ft}^3)(2\ \text{ft}^3)$$

$W_{Al} = 337$ lb

1F3, HYDRAULIC JACK

All calculations require laboratory data.

1F4, MANOMETERS

2. Pressure Difference = $(\rho_{Hg})(h_{Hg}) = (\rho_{oil})(h_{oil})$

$(13.6\ \text{g/cm}^3)(76\ \text{cm}) = (.90\ \text{g/cm}^3)((h_{oil})$

$h_{oil} = 1148\ \text{cm} = 11.48\ \text{m}$

3. $p_2 - p_1 = (\rho h)_{Hg}$

$2 \text{ psi} = (0.491 \text{ lb/in}^3)\ (h)$

$h = 4.07 \text{ in}$

4. $p_2 - p_1 = (\rho h)_{water}$

$2 \text{ lb/in}^2 = (.0361 \text{ lb/in}^3)\ (h)$

$h = 55.4 \text{ in}$

5. $p - p_{atm} = \rho_{Hg}\ h$

$p - 14.7 \text{ lb/in}^2 = (0.491 \text{ lb/in}^3)(12.0 \text{ in})$

$p = 20.6 \text{ lb/in}^2$

9. (2) $11.5 \text{ m } (\frac{3.28 \text{ ft}}{1 \text{ m}}) = 37.7 \text{ ft; } (453 \text{ in})$

(3) $4.0 \text{ in } (\frac{2.54 \text{ cm}}{1 \text{ in}}) = 10.3 \text{ cm}$

(5) $2.06 \text{ lb/in}^2\ (\frac{1.013 \text{ N/m}^2}{14.7 \text{ lb/in}^2}) = 1.42 \text{ N/m}^2$

1E1, POTENTIAL DIFFERENCE AND CHARGE FLOW

No calculations required.

1E2, SERIES AND PARALLEL VOLTAGE SOURCES

4. (a) Voltage across parallel connection is 2.5 volts.

$V_{ab} = V_1 + V_2$ (when in series)

$V_{ab} = 2.5 \text{ V} + 3.5 \text{ V} = 6 \text{ V}$

(b) The (-)1.5 V emf and (-)4.5 V emf are in series and are equivalent to one (-)6.0 V emf. The voltage across the parallel connection is (-)6.0 V

$V_{ab} = -6.0 \text{ V} + 2.0 \text{ V} = -4.0 \text{ V}$

(c) Improper connections.

(d) Improper connections.

1E3, ELECTRIC FORCES AND FIELDS

2. $F = \frac{kQ_1Q_2}{R^2}$

$$F = \frac{(9 \times 10^9 \frac{Nm^2}{C^2})(1.602 \times 10^{-19}\ C)(1.602 \times 10^{-19}\ C)}{(10^{-10}\ m)}$$

$$F = 2.31 \times 10^{-8}\ N$$

3. $E = \frac{V}{d}$

$$= \frac{100\ V}{10^{-3}\ m}$$

$$E = 10^5\ V/m = 10^5\ N/C$$

$$Q = CV$$

$$= (10 \times 10^{-6}\ f)(100\ V)$$

$$Q = 10^{-3}\ C$$

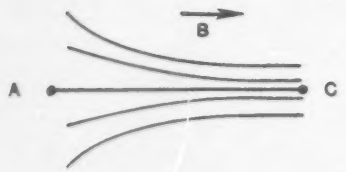
$$E = F/Q$$

$$F = EQ = 10^5\ N/C\ (1.602 \times 10^{-19}\ C)$$

$F = 1.602 \times 10^{-14}$ N toward the negatively charged plate.

1E4, MAGNETIC FORCES AND FIELDS

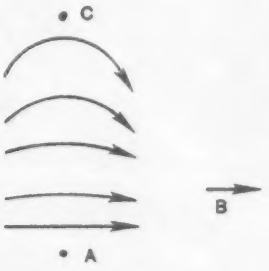
5.



Magnetic field increases from A to C.

Magnetic force on electron is zero since motion of electron is parallel to field lines.

Electron remains undeflected.



Magnetic force decreases since $\vec{B}$ decreases.

The electron is deflected out of the page.

6. Downward.

7. The electron flow is out of the page.

1E5, LEAD ACID STORAGE BATTERY

No calculations required.

1T1, THERMOMETERS

3. $T_F = \frac{9}{5} T_C + 32$

$= \frac{9}{5} (1063) + 32$

$T_F = 1945°F$

4. $T_C = \frac{5}{9} (T_F - 32)$

$= \frac{5}{9} (72-32)$

$T_C = 22.2°C$

5. (a) $T_C = \frac{5}{9} (T_F - 32)$

$= \frac{5}{9} (-32 - 32)$

$T_C = -35.6°C$

(b) $T_K = T_C + 273$

$350 = T_C + 273$

$T_C = 77°C$

(c) $T_C = \frac{5}{9} (T_F - 32)$

$= \frac{5}{9} (28 - 32)$

$T_C = -2.2°C$

(d) $T_K = T_C + 273$

$1300 = T_C + 273$

$T_C = 1027°C$

1T2, TEMPERATURE DIFFERENCE AND HEAT FLOW

2. $Q_H = \frac{kA\,(T_2 - T_1)}{d}$

$$= \frac{\left(9.0\ \frac{\text{Btu} \times \text{in}}{\text{h} \times \text{ft}^2 \times \text{F}^\circ}\right)(5\ \text{ft} \times 8\ \text{ft})(58^\circ\text{F} - 18^\circ\text{F})}{4\ \text{in}}$$

$$Q_H = 3600\ \frac{\text{Btu}}{\text{h}}$$

1T3, THERMAL STRESS

5. $F = A(E)\,\alpha\,(T - T_0)$; so $T - T_0 = \frac{F}{A(E)\,\alpha}$

$$T - T_0 = -\frac{4.7 \times 10^6\ \text{dynes}}{(\text{cm}^2)(23.5 \times 10^{-6}/\text{C}^\circ)(6.9 \times 10^{11}\ \text{dynes/cm}^2)}$$

(The minus sign corresponds to a contraction of the wire)

$T - T_0 = 29.0\text{C}^\circ$; so the final temperature is -4.0°C.

6. $L - L_0 = L_0\,\alpha\,(T - T_0)$

$= (2\ \text{miles})\,(9.6 \times 10^{-6}/\text{C}^\circ)(40\text{C}^\circ)$

$L - L_0 = 7.68 \times 10^{-4}\ \text{miles} \approx 4.1\ \text{ft}$

2-0, WORK

4. $W = F\ell$

$= (70\ \text{N})(500\ \text{m})$

$W = 35{,}000\ \text{J}$

5. $W = F\ell$; so $F = \frac{W}{\ell}$

$F = \frac{45\ \text{ft}\cdot\text{lb}}{15\ \text{ft}}$

$F = 3\ \text{lb}$

6. $W = \tau\theta$; so $\theta = \frac{W}{\tau}$; π radians = 180°

$\theta = \frac{12\ \text{ft}\cdot\text{lb}}{280\ \text{ft}\cdot\text{lb}}$

$\theta = 0.043$ radians; $\theta = 0.043\ \text{rad}\left(\frac{180^\circ}{\pi\ \text{rad}}\right) = 2.46^\circ$

8. $W = \tau\theta$

$= (70\ N\cdot m)(4.5\ rev)\left(\frac{2\pi\ rad}{rev}\right)$

$W = 1979\ joules = (1979\ N\cdot m)\left(\frac{1\ lb}{4.45\ N}\right)\left(\frac{3.28\ ft}{m}\right) = 1459\ ft\cdot lb$

9. $W = (\Delta p)\ V$, so $\Delta p = \frac{W}{V}$

$\Delta p = \frac{13{,}000\ J}{18\ m^3} = 722\ N/m^2$

$\Delta p = (722\ N/m^2)\left(\frac{1\ lb}{4.45\ N}\right)\left[\frac{(1\ m)^2}{(3.28\ ft)^2}\right] = 15.1\ lb/ft^2$

10. $W = \Delta p(V)$

$= (0.25\ lb/in^2)\left(\frac{144\ in^2}{ft^2}\right)(20\ ft \times 30\ ft \times 8\ ft)$

$W = 172{,}800\ ft\cdot lb$

11. $H = mc\Delta T$

$= (500\ g)(0.093\ cal/gC°)(95°C - 29°C)$

$H = 3069\ cal$

12. $Q_H = KA\ \frac{\Delta T}{\Delta L}$

$\frac{Q_H}{4} = \left(0.30\ \frac{Btu\cdot in}{hr\cdot ft^2\cdot F°}\right)(45\ ft^2)\left(\frac{70°F - 40°F}{2.5\ in}\right)$

$Q_H = 648\ Btu/hr$

13. $W = VQ$, so $Q = \frac{W}{V}$

$Q = \frac{1800\ J}{12\ V}$

$Q = 150\ C$

14. $H = mc\Delta T$; $m = \frac{H}{c\Delta T}$ 1 Btu = 252 cal

$m = \frac{(90\ Btu)(252\ cal/Btu)}{(1\ cal/g\cdot C°)(50\ C°)}$

$m = 453.6\ g = 1\ lb$

2M1, WORK DONE ON AN ELEVATOR

2. $W = F\ell$

$= (35\ N)(15\ m)$

$W = 525\ J$

3. $W = F\ell$

$= [3000\ lb \times 12\ (150\ lb)]\ (20)(25\ ft)$

$W = 2.4 \times 10^6\ ft \cdot lb$

$(2.4 \times 10^6\ ft \cdot lb)\ (\frac{1\ J}{0.7373\ ft \cdot lb}) = 3.26 \times 10^6\ J$

4. (a) $F = mg \sin\theta$, $\sin\theta = \frac{opp}{hyp} = \frac{4\ ft}{\sqrt{(4\ ft)^2 + (20\ ft)^2}} = 0.196$

$F = (800\ lb)(0.196) = 156.8\ lb$

(b) $W = F\ell$; $\ell = \sqrt{(4\ ft)^2 + (20\ ft)^2} = 20.4\ ft$

$W = (156.8\ lb)(20.4\ ft) = 3198\ ft \cdot lb$

(c) $W = F\ell$

$= (8000\ lb)(4\ ft)$

$W = 3200\ lb$

5. Since the piano is not displaced by the men during the 1 minute interval no work is accomplished. (Although energy is expended).

6. $W = F\ell$, F = Normal Force = $mg \cos\theta$, $\cos\theta = \frac{adj}{hyp}$, $\ell = hyp$

$= (800\ lb)(\frac{20\ ft}{hyp})(hyp)$

$W = 16{,}000\ ft \cdot lb$

2M2, WORK DONE BY A WINCH

2. $W_{in} = F_{in}\ r_{in}\ \theta_{in}$; $W_{out} = F_{out}\ r_{out}\ \theta_{out}$; $\eta = \frac{W_{out}}{W_{in}}\ (100)$

(a) $W_{in} = (100\ N)(6.25\ m)(15\ rev)(\frac{2\pi\ rad}{rev}) = 2356.2\ J$

(b) $W_{out} = (6825\ N)(0.05\ m)(1\ rev)(\frac{2\pi\ rad}{rev}) = 2144.1\ J$

(c) $\eta = \frac{2144.1\ J}{2356.2\ J}\ (100) = 91\%$

(d) $W_{Frict.} = W_{in} - W_{out} = 2356.2\ J - 2144.1\ J = 212.1\ J$

3. $W_{in} = F_{in}\, r_{in}\, \theta_{in} = W_{out} = F_{out}\, r_{out}\, \theta_{out}$ (For a 100% eff. winch)

(a) $F_{out} = \dfrac{F_{in}\, r_{in}\, \theta_{in}}{r_{out}\, \theta_{out}} = \dfrac{(50\ N)(0.35\ m)(1\ rev)}{(0.08\ m)(1\ rev)}$

$F_{out} = 218.75\ N$

(b) The length of rope taken up is just enough to wrap around the circumference of the winch drum.

Circumference of drum = $2\pi r$

$C = 2\pi\ (0.08\ m)$

$C = 0.503\ m$

2F1, WORK DONE BY A WATER PUMP

4. $W_{out} = V\ (\rho_W)h \qquad W_{in} = VIt; \quad \eta = \dfrac{W_{out}}{W_{in}}\ (100) = \dfrac{\rho_W h}{VIt}\ (100)$

$W_{out} = (1000\ gal)\left(\dfrac{1\ ft^3}{7.48\ gal}\right)\left(\dfrac{62.4\ lb}{ft^3}\right)(30\ ft) = 2.503 \times 10^5\ ft{\cdot}lb$

$W_{out} = 2.503 \times 10^5\ ft{\cdot}lb\ \left(\dfrac{4.45\ N}{lb}\right)\left(\dfrac{1\ m}{3.28\ ft}\right) = 3.396 \times 10^5\ J$

$75\% = \dfrac{3.396 \times 10^5\ J}{(24\ V)(5\ A)(t)}\ (100); \quad t = \dfrac{(3.396 \times 10^5\ J)(100)}{(24\ V)(5\ A)(75)} = 3.77 \times 10^3\ J$

5. $W_{out} = V\ (\rho_W)h \qquad \eta = \dfrac{W_{out}}{VIt}\ (100), \qquad \text{so } I = \dfrac{(W_{out})(100)}{Vt(\eta)}$

$W_{out} = (200\ kg)\left(\dfrac{9.8\ N}{kg}\right)(40\ m) = 78{,}400\ J$

$I = \dfrac{(78{,}400\ J)(100)}{(110\ V)(120\ s)(80)} = 7.42\ A$

2F2, WORK DONE BY A HYDRAULIC LIFT

3. W = weight x height

$= 1200\ lb\ (8\ in)\left(\dfrac{1\ ft}{12\ in}\right)$

$W = 800\ ft{\cdot}lb$

4. $W = P \times A \times L$

$= (692\ lb/in^2)(0.25\ in^2)(1.5\ in)\left(\dfrac{1\ ft}{12\ in}\right)(38)$

$W = 821.75\ ft{\cdot}lb$

5. $\eta = \frac{W_{out}}{W_{in}} (100)$

$= \frac{800 \text{ ft·lb}}{821.75 \text{ ft·lb}} (100)$

$\eta = 97.4\%$

2T1, HEAT ENERGY REQUIRED FOR A TEMPERATURE INCREASE

5. $m_s c_s (T_s - T_2) = (m_w + m_c c_c)(T_2 - T_1)$

$T_2 = \frac{m_s c_s T_s + (m_w + m_c c_c) T_1}{m_w + m_c c_c + m_s c_s}$

$T_2 = \frac{100 \text{ g } (0.22 \text{ cal/g·°C})(180°C) + (200 \text{ cal/°C} + 152 \text{ cal/°C})(10°C)}{200 \text{ cal/°C} + 152 \text{ cal/°C} + 100 \text{ g } (0.22 \text{ cal/g·°C})} = 20°C$

6. $m_G C_{Liq} (T_G - 30°C) + m_G C_{Sol} (30°C - T_2) + m_G L_f = (m_w + m_c c_c)(T_2 - T_1)$

$L_f = \frac{(m_w + m_c c_c)(T_2 - T_1) - m_G C_{Liq}(T_G - 30°C) - m_G C_{Sol} (30°C - T_2)}{m_G}$

$= \frac{(100 \frac{\text{cal}}{°C} + 46.35 \text{ cal/°C})(20° - 5°) - 100 \text{ g } (0.0954 \frac{\text{cal}}{\text{g·°C}})(50° - 30°) - 100 \text{ g}(0.0895 \frac{\text{cal}}{\text{g·°C}})(30° - 20°)}{100 \text{ g}}$

$L_f = 19.15 \text{ cal/g}$

7. Water Equivalent $= m_c c_c$

Water Equivalent $= 100 \text{ g}(0.115 \frac{\text{cal}}{\text{g·°C}}$

Water Equivalent $= 11.5 \text{ cal/°C}$

2T2, HEAT ENERGY REQUIRED FOR MELTING

2. $Q = mL$

$= (2500 \text{ g})(5.86 \text{ cal/g})$

$Q = 14{,}650 \text{ cal}$

3. $Q = mL$

$= (500 \text{ g})(79.7 \text{ cal/g})$

$Q = 39{,}850 \text{ cal}$

2T3, HEAT ENERGY REQUIRED FOR BOILING

4. $L_v = 539$ cal/g

$L_f = 79.7$ cal/g

Heat required to raise one gram of water from 0°C to 100°C can be calculated with the formula $H = mc(\Delta T)$.

$H = (1\ g)(1\ cal/g \cdot C°)(100\ C°) = 100$ cal

5. $L_v = \frac{\text{total calories required}}{\text{mass}}$

$= \frac{10{,}200\ cal}{50\ g}$

$L_v = 204$ cal/g

2T4, FUNDAMENTALS OF AIR CONDITIONING

2. $EER = \frac{Btu/h}{wattage}$

$= \frac{18{,}000\ Btu/h}{2250\ W}$

EER = 8

3. Total Cost = (kW)(cost/kWh)(h)

(a) Total Cost = (1.559 kW)(6¢/kWh)(24 h)

Total Cost = 224.5¢ ≅ $2.25

(b) Total Cost = (2.250 kW)(6¢/kWh)(24 h)

Total Cost = 324¢ = $3.24

(c) Total Cost = (2.665 kW)(6¢/kWh)(24 h)

Total Cost = 383.8¢ ≅ $3.84

2. $v = \frac{d}{t}$

$= \frac{3200 \text{ km}}{3.5 \text{ h}}$

$v = 914.3 \text{ km/h}$

3. $a = \frac{v_2 - v_1}{t}$

$= \frac{0 \text{ ft/s} - (55 \text{ mi/h})(\frac{5280 \text{ ft}}{\text{mi}})(\frac{1 \text{ h}}{3600 \text{ s}})}{16.3 \text{ s}}$

$a = -4.95 \text{ ft/s}^2$ (negative sign indicates a deceleration)

4. $v = \frac{d}{t}$, so $t = \frac{d}{v}$

$t = \frac{250 \text{ mi}}{55 \text{ mi/h}}$

$t = 4.55 \text{ h}$

5. $F = ma$, so $a = \frac{F}{m}$; $a = \frac{v_2 - v_1}{t}$, so $v_2 = at + v_1$

$a = \frac{200 \text{ N}}{100 \text{ kg}} = 2 \text{ m/s}^2$

$v_2 = (2 \text{ m/s}^2)(3 \text{ s}) + (0 \text{ m/s}) = 6 \text{ m/s}$

6. $\alpha = \frac{\omega_2 - \omega_1}{t}$

$= \frac{(1750 \text{ r/min})(\frac{2\pi \text{ rad}}{\text{r}})(\frac{1 \text{ min}}{60 \text{ s}}) - (0 \text{ rad/s})}{25 \text{ s}}$

$\alpha = 7.33 \text{ rad/s}^2$

7. $\omega = \frac{\theta}{t}$, so $t = \frac{\theta}{\omega}$

$t = \frac{1 \text{ rev}}{5000 \text{ rev/min}}$

$t = 2 \times 10^{-4} \text{ min}$ or $1.2 \times 10^{-2} \text{ s}$

8. $Q_V = \frac{V}{t}$, so $t = \frac{V}{Q_V}$

$t = \frac{20 \text{ gal}}{(15 \text{ gal/min})(\frac{1 \text{ gal}}{3.786 \text{ ℓ}})}$

$t = 5.05 \text{ min}$

9. $Q_H = \frac{H}{t}$, so $H = Q_H(t)$

$H = (10{,}000 \text{ Btu/h})(24 \text{ h})(\frac{20}{100})$

$H = 48{,}000 \text{ Btu}$

10. $I = \frac{Q}{t}$, so $Q = It$

$Q = (0.5\ C/s)(12\ h)(\frac{3600\ s}{h})$

$Q = 21{,}600\ C$

3M1, GRAPHIC APPROACH TO LINEAR MOTION

2. (a) $d = vt$

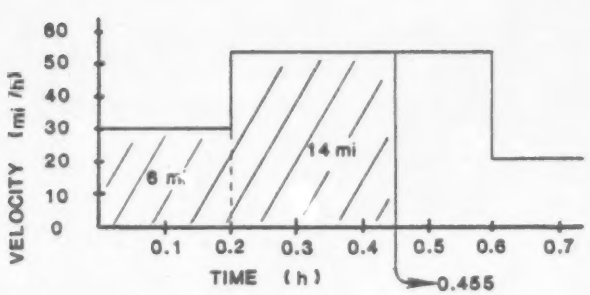
$d = (30\ mi/h)(0.20\ h) = 6\ mi$

(b) $d_{tot} = v_1t_1 + v_2t_2 + v_3t_3$

$d_{tot} = (30\ mi/h)(0.20\ h) + (55\ mi/h)(0.40\ h) + (20\ mi/h)(0.10\ h)$

$d_{tot} = 30\ mi$

(c)



(d) It takes 0.2 h to travel the 1st 6 mi (see part [a]). The next 14 mi are traveled when the car is going 55 mi/h. The time it takes to travel 14 miles at a speed of 55 mi/h must be determined.

$t = \frac{d}{v}$

$t = \frac{14\ mi}{55\ mi/h} = 0.255\ h$

∴ The time it takes to travel 20 mi = 0.2 hr + 0.255 h = 0.455 h

(e) See graph in part (c).

3. (a) Approximately 0.007 h (from graph).

(b) d_B = area under car B's curve = $(40\ mi/h)(0.007\ h) = 0.28\ mi$

d_A = area under car A's curve = $\frac{1}{2}(40\ mi/h)(0.007\ h) = 0.14\ mi$

$d_B - d_A = 0.28\ mi - 0.14\ mi = 0.14\ mi$

So car B is 0.14 mi ahead of car A

(c) $d_B = (40\ mi/h)(0.01\ h) = 0.4\ mi$

$d_A = \frac{1}{2}(60\ mi/h)(0.01\ h) = 0.3\ mi$

so car B is still ahead by 0.1 mi.

(d) $d_B = d_A$ when $(40\ mi/h)(t) = \frac{1}{2}(60\ mi/h)(0.01\ h) + (60\ mi/h)(t - 0.01)$

$$t = \frac{(60\ mi/h)(0.01\ h) - \frac{1}{2}(60\ mi/h)(0.01\ h)}{20\ mi/h} = 0.015\ h$$

(e) $d = d_B = d_A$

$= (40\ mi/h)(0.015\ h) = 0.6\ mi$ or

$d = \frac{1}{2}(60\ mi/h)(0.01\ h) + (60\ mi/h)(0.015\ h - 0.01\ h) = 0.6\ mi$

3M2, VELOCITY AT A CONSTANT ACCELERATION

1. $v_2 = v_1 + at$

$= 0 + (9.8\ m/s^2)(5\ s)$

$v_2 = 49\ m/s$

2. $a = \frac{v_2 - v_1}{t}$; 40 km/hr = 11.1 m/s, 50 km/hr = 13.9 m/s

$a = \frac{13.9\ m/s - 11.1\ m/s}{30\ s} = 0.093\ m/s^2$

3. $t = \frac{v_2 - v_1}{a}$

$= \frac{0 - 16\ m/s}{-0.8\ m/s^2}$

$t = 20\ s$

4. $a = \frac{v_2 - v_1}{t}$

$a = \frac{12.6\ m/s - 0\ m/s}{8\ s} = 1.58\ m/s^2$

$t = \frac{v_2 - v_1}{a} = \frac{28\ m/s - 12.6\ m/s}{1.58\ m/s^2} = 9.75\ s$

5. $v_2 = v_1 + at$

$= 6.2\ m/s + (-9.8\ m/s^2)\ 1.2\ s$

$v_2 = -5.56\ m/s$ (down)

6. $a = \frac{v_2 - v_1}{t}$; $\longrightarrow$, + ; $\longleftarrow$, -

$a = \frac{(-12.8\ m/s) - (2.3\ m/s)}{4.8\ s} = -3.15\ m/s^2$ (left)

3M3, DISPLACEMENT AT CONSTANT ACCELERATION

1. $s = v_1 t + \frac{1}{2} at^2$ (choose upward as positive direction)

$s = (0) + \frac{1}{2} (-9.8 \text{ m/s}^2)(3 \text{ s})^2$

$s = -44.1 \text{ m}$

2. $v_2^2 = v_1^2 + 2as$ (choose upward as positive)

$v_2 = \sqrt{(0)^2 + 2 (-9.8 \text{ m/s}^2)(-5.7 \text{ m})}$

$v_2 = 10.57 \text{ m/s}$

3. (a) $v_2^2 = v_1^2 + 2as$, so $v_1^2 = v_2^2 - 2as$

$v_1^2 = (8.6 \text{ m/s})^2 - 2(-9.8 \text{ m/s}) (5.1 \text{ m}) = 173.92 \text{ m}^2/\text{s}^2$

$v_1 = \sqrt{173.92 \text{ m}^2/\text{s}^2} = 13.2 \text{ m/s}$

(b) $v_2^2 = v_1^2 + 2as$, $s = \frac{v_2^2 - v_1^2}{2a}$

$s = \frac{(0)^2 - (13.2 \text{ m/s})^2}{2 (-9.8 \text{ m/s}^2)}$

$s = 8.9 \text{ m}$

(c) $s = v_1 t + \frac{1}{2} at^2$, since $v_1 = 0$, $s = \frac{1}{2} at^2$, so $t = \sqrt{\frac{2s}{a}}$

$t = \sqrt{\frac{2(-8.9 \text{ m})}{-9.8 \text{ m/s}^2}}$

$t = 1.35 \text{ s}$

4. $s = \frac{(v_1 + v_2) t}{2}$

$= \frac{(30 \text{ m/s} + 0)(10 \text{ s})}{2}$

$s = 150 \text{ m}$

3M4, ACCELERATION OF A MASS BY A CONSTANT FORCE

1. $F_2 - F_1 = ma$, $a = \frac{F_2 - F_1}{m}$

$a = \frac{100 \text{ N} - 20 \text{ N}}{10 \text{ kg}} = 8 \text{ m/s}^2$

2. $F = ma$, $m = \frac{F}{a}$

$m = \frac{50 \text{ N}}{5 \text{ m/s}^2} = 10 \text{ kg}$

3. $v_2 = v_1 + \frac{F}{m} t$, $v_1 = 0$

$v_2 = \frac{25\ N}{10\ kg} (2\ s)$

$v_2 = 5\ m/s$

4. $v_f^2 = v_i^2 + 2 (\frac{F}{m}) s$; $F = \frac{(v_f^2 - v_i^2)\ m}{2\ s}$

$F = \frac{[0 - (10\ m/s)^2](4000\ kg)}{2\ (20\ m)}$

$F = -10{,}000\ N$

5. $F_{net} = F_1 + F_2$

$F_{net} = (1000\ N) + (1000\ N) = 2000\ N$

6. $F_{net} = F_{winch} - F_{gravity} = 10{,}000\ N - (1100)(9.8)\ N$

$F_{net} = -780\ N$

$F_{net} = ma$, $a = \frac{F_{net}}{m} = \frac{-780\ N}{1100\ kg}$

$a = -0.71\ m/s^2$ (The minus sign means the elevator is accelerating downward.)

3M5, ROTATIONAL MOTION

2. $v = r\omega$

(a) $v = (0.15\ m)(78\ rpm)(\frac{2\pi\ rad}{rev})(\frac{1\ min}{60\ s}) = 1.23\ m/s$

(b) $v = (0.074\ m)(78\ rpm)(\frac{2\pi\ rad}{rev})(\frac{1\ min}{60\ s}) = 0.604\ m/s$

3. (a) $v = r\omega$, so $\omega = \frac{v}{r}$

$\omega = \frac{25\ m/s}{0.38\ m} = 65.8\ rad/s$

(b) $\omega_2^2 = \omega_1^2 + 2\alpha\theta$, so $\alpha = \frac{\omega_2^2 - \omega_1^2}{2\theta}$

$\alpha = \frac{(0\ rad/s)^2 - (65.8\ rad/s)^2}{(2)(30\ turns)(\frac{2\pi\ rad}{turn})} = -11.5\ rad/s^2$

(c) $s = r\theta$

$s = (0.38\ m)(30\ turns)(\frac{2\pi\ rad}{turn}) = 71.6\ m$

4. $\theta = \frac{1}{2} (\omega_1 + \omega_2)(t)$

$= \frac{1}{2} (160\ rev/min + 0\ rev/min)(25\ h)(\frac{60\ min}{h})$

$\theta = 120{,}000\ rev$

3M6, RADIAL ACCELERATION AND CENTRIPETAL FORCE

1. (a) $v = \omega r$

$= (\frac{1 \text{ rev}}{3 \text{ s}})(\frac{2\pi \text{ rad}}{\text{rev}})(6 \text{ ft})$

$v = 12.6 \text{ ft/s}$

(b) $a_c = \frac{v^2}{r}$

$= \frac{(12.6 \text{ ft/s})^2}{6 \text{ ft}}$

$a_c = 26.5 \text{ ft/s}^2$

(c) $F_c = ma_c$

$= \frac{50 \text{ lb}}{32 \text{ ft/s}^2} (26.5 \text{ ft/s}^2)$

$F_c = 41.4 \text{ lb}$

5. $mg = mv^2/r$; $g = v^2/r$

$v = \sqrt{gr} = \sqrt{(32 \text{ ft/s}^2)(16 \text{ ft})}$

$v = 22.6 \text{ ft/s}$

3F1, FLOW RATE MEASUREMENT WITH A VENTURI METER

2. $V = Av$

$V = A_1v_1$; $V = A_2v_2$, so $A_2v_2 = A_1v_1$,

$\therefore \frac{v_1}{v_2} = \frac{A_2}{A_1} = \frac{(\pi)(0.65 \times 10^{-2})^{2/4}}{(\pi)(1.72 \times 10^{-2})^{2/4}} = 0.143$

3. $v_1 = \sqrt{\frac{2gh}{\left(\frac{A_1}{A_2}\right)^2 - 1}}$

$= \sqrt{\frac{2(9.8\ m/s^2)(0.06\ m)}{\left[\frac{\pi(1.72 \times 10^{-2})^{2/4}}{\pi(0.65 \times 10^{-2})^{2/4}}\right]^2 - 1}}$

$v_1 = 0.157$ m/s

3E1, ELECTRIC CURRENT

2. $I = \frac{Q}{t}$, so $Q = It$

$Q = (16\ C/s)(25 \times 10^{-3}\ s)$

$Q = 0.4$ C

3. $I = \frac{Q}{t}$

$I = \frac{10\ C}{60\ s}$

$I = 0.167$ C/s

4. $I = \frac{Q}{t}$, $\therefore \quad t = \frac{Q}{I}$

$t = \frac{0.5\ C}{25 \times 10^{-3}\ C/s}$

$t = 20$ s

3E2, FREQUENCY

2 $f = \frac{n}{t}$; $k = \frac{n}{d}$

$f = \frac{1\ car}{4\ s} = 0.25$ cars/s

$k = \frac{1\ car}{20\ m} = 0.05$ car/m

3. $k = \frac{n}{d}$

$= \frac{1}{0.002 \times 10^{-3}\ m}$

$k = 5 \times 10^{5}$ grooves/m

4. $T = \frac{1}{f}$

(a) $T = \frac{1}{50/s} = 0.02\ s$

(b) $T = \frac{1}{50 \times 10^{3}/s} = 2 \times 10^{-5}\ s$

(c) $T = \frac{1}{50 \times 10^{6}/s} = 2 \times 10^{-6}\ s$

5. The smallest unit of time that can be measured by any repetitive event is equal to the period of that event.

(a) $T = 2\pi\sqrt{\ell/g}$

$T = 2\pi\sqrt{\frac{1.5\ m}{9.8\ m/s^{2}}} = 2.46\ s$

(b) $T = \frac{1}{f}$

$T = \frac{1}{5.2 \times 10^{6}/s} = 1.92 \times 10^{-7}\ s$

(c) $T = \frac{1}{f}$

$T = \frac{1}{5 \times 10^{14}/s} = 2 \times 10^{-15}\ s$

ET1, HEATING AND COOLING RATE

3. $r = \frac{T_2 - T_1}{t_2 - t_1}$

$r_1 = \frac{150°F - 200°F}{5\ min} = -10F°/min$

$r_2 = \frac{110°F - 200°F}{10\ min} = -9F°/min$

$r_3 = \frac{80°F - 200°F}{15\ min} = -8F°/min$

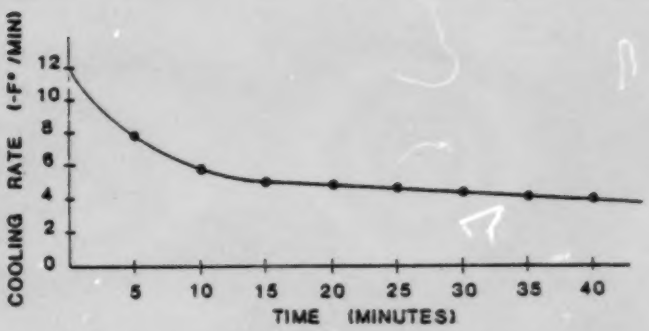
$r_4 = \frac{60°F - 200°F}{20\ min} = -7F°/min$

$r_5 = \frac{50°F - 200°F}{25\ min} = -6F°/min$

$r_6 = \frac{44°F - 200°F}{30\ min} = -5.2F°/min$

$r_7 = \frac{40°F - 200°F}{35\ min} = -4.57F°/min$

$r_8 = \frac{38°F - 200°F}{40\ min} = -4.05F°/min$



4. $r = \frac{T_2 - T_1}{t_2 - t_1}$, $T_2 = r(t_2 - t_1) + T_1$

$r = \frac{200°F - 70°F}{10\ s} = 13F°/s$

$T_2 = (13F°/s)(20\ s) + 70°F$

$T_2 = 330°F$

3T2, RATE OF HEAT CONDUCTION

4. $Q_H = \frac{H}{t}$; $H = mc\Delta T$; mass of 900 cm^3 of water = 900 g

$= \frac{900\ g\ (1\ cal/g \cdot C°)(40C°)}{(15)(60)\ s}$

$Q_H = 40$ cal/s

5. $Q_H = UA\ (T_2 - T_1)$

$= (0.240\ \frac{Btu}{h \cdot ft^2 \cdot F°})\ 480\ ft^2\ (70F°)$

$Q_H = 8064$ Btu/h

If the wall had 3 inches of insulation the rate of heat conduction would be reduced by the following factor:

$\frac{U_{3\ inches}}{U_{0\ inches}} = \frac{0.072}{0.240} = 0.3$

$\therefore$ Q_H would be 2419 Btu/h.

4-0, MOMENTUM

2. $\vec{p} = m\vec{v}$

$\vec{p} = (2\text{b}) \text{ lb})(\frac{1 \text{ slug}}{32 \text{ lb}})(5 \text{ ft/s})$

$\vec{p} = 39.1 \text{ slug·ft/s}$

4. Momentum Before = Momentum After

(mv_1) proton $= (-mv_2)$ proton $+ (mv_2)$ unknown

$(1.67 \times 10^{-27} \text{ kg})(5 \times 10^6 \text{ m/s}) = -(1.67 \times 10^{-27} \text{ kg})(3 \times 10^6 \text{ m/s}) + m\ (1.5 \times 10^6 \text{ m/s})$

$m = 8.9 \times 10^{-27} \text{ kg}$

5. Momentum Before = Momentum After

$m_1\vec{v}_1 = (m_1 + m_2)\vec{v}_2$, $\therefore \vec{v}_2 = \frac{m_1\vec{v}_1}{m_1 + m_2}$

$\vec{v}_2 = \frac{(0.5 \text{ kg})(700 \text{ m/s})}{(0.5 \text{ kg} + 20 \text{ kg})} = 17.1 \text{ m/s}$

6. (a) $\vec{L} = I\vec{\omega}$; $I = \frac{1}{2} mr^2$

$\vec{L} = \frac{1}{2} (5 \text{ kg})(0.10 \text{ m})^2(1800 \text{ rev/min})(\frac{2\pi \text{ rad}}{\text{rev}})(\frac{1 \text{ min}}{60 \text{ s}})$

$\vec{L} = 4.71 \text{ kg·m}^2/\text{s}$

(b) $\Delta L = I\ (\Delta\omega)$

$= \frac{1}{2} (5 \text{ kg})(0.10 \text{ m})^2(2400 \text{ rev/min} - 1800 \text{ rev/min})(\frac{2\pi \text{ rad}}{\text{rev}})(\frac{1 \text{ min}}{60 \text{ s}})$

$\Delta L = 1.57 \text{ kg·m}^2/\text{s}$

(c) $\Delta L = \tau(\Delta t)$; $\therefore \tau = \frac{\Delta L}{\Delta t}$

$\tau = \frac{1.57 \text{ kg·m}^2/\text{s}}{30 \text{ s}}$

$\tau = 0.0523 \frac{\text{kg·m}^2}{\text{s}^2} \text{ (N·m)}$

8. $F = 2\ (\frac{m}{t})v$

$= 2(5 \text{ kg/s})(7 \text{ m/s})$

$F = 70 \text{ N}$

4M1, ANGULAR MOMENTUM OF A FLYWHEEL

2. $I = \frac{1}{2} mr^2$

$= \frac{1}{2} (3.6 \text{ kg})(\frac{0.6}{2} \text{ m})^2$

$I = 0.162 \text{ kg}\cdot\text{m}^2$

3. $I = mr^2$

$= (0.68 \text{ kg})(0.12 \text{ m})^2$

$I = 9.8 \times 10^{-3} \text{ kg}\cdot\text{m}^2$

4. $L = I\omega$, $I = mr^2$

$L = (0.1 \text{ kg})(1 \text{ m})^2(\frac{1 \text{ rev}}{1.2 \text{ s}})(\frac{2\pi \text{ rad}}{\text{rev}})$

$L = 0.52 \frac{\text{kg}\cdot\text{m}^2}{\text{s}}$

5. $L = I\omega$, $L = \tau t$, $I = \frac{1}{2} mr^2$

$L = \frac{1}{2} (4.8 \text{ kg})(0.16 \text{ m})^2(1500 \text{ rev/min})(\frac{2\pi \text{ rad}}{\text{rev}})(\frac{1 \text{ min}}{60 \text{ s}})$

$L = 9.65 \text{ kg}\cdot\text{m}^2/\text{s}$

4M2, IMPULSE AND MOMENTUM

3. (a) $\Delta p = mv_2 - mv_1 = F(\Delta t)$; so $\Delta v = \frac{F(\Delta t)}{m}$

$\Delta v = \frac{(16 \text{ N})(3.5 \text{ s})}{2 \text{ kg}} = 28 \text{ m/s}$

(b) $a = \frac{F}{m} = \frac{\Delta v}{\Delta t}$, so $\Delta v = (\frac{F}{m})\Delta t$

$\Delta v = (\frac{16 \text{ N}}{2 \text{ kg}})(3.5 \text{ s}) = 28 \text{ m/s}$

4. Δp = change in momentum $= F(\Delta t) = mv_2 - mv_1$, so $m = \frac{F(\Delta t)}{v_2 - v_1}$

$m = \frac{10.5 \text{ N}\cdot\text{s}}{(16 \text{ m/s} - 0 \text{ m/s})}$

$m = 0.656 \text{ kg}$

5. $F = \frac{\Delta p}{\Delta t}$, so $\Delta t = \frac{\Delta p}{F}$

$\Delta t = \frac{1000 \text{ kg (m/s)}}{50 \text{ N}}$

$\Delta t = 20 \text{ s}$

4M3, CONSERVATION OF MOMENTUM IN COLLISIONS

3. $m_1v_1 + m_2v_2 = (m_1 + m_2)\,v$; $\quad v = \dfrac{m_1v_1 + m_2v_2}{m_1 + m_2}$

$$v = \frac{(9980\text{ kg})(12\text{ m/s}) + (9072\text{ kg})(0\text{ m/s})}{9980\text{ kg} + 9072\text{ kg}}$$

$v = -6.29$ m/s (in the direction that the loaded streetcar was traveling.)

4M4, GYROSCOPES

3. $\tau = \Omega L$; $L = I\omega$, $\tau = \Omega I \omega$

$$\tau = (0.3\text{ rad/s})(900\text{ g}\cdot\text{cm}^2)(5000\text{ rev/min})\left(\frac{2\pi\text{ rad}}{\text{rev}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)$$

$\tau = 141{,}372$ dyne·cm

6. The nose is pulled up.

4F1, ROCKET ENGINES

1. (a) I = (thrust force)(time) = (length x width)

$= (1\ N)(0.2\ s)$

$I = 0.2\ N \cdot s$

(b) 24 whole squares

(c) 8 3/4 fractional parts

(d) $I_{total} = (0.2\ \frac{N \cdot s}{sq})(8\ 3/4 + 24)$ squares

$I_{total} = 6.55\ N \cdot s$

2. $I_{sp} = \frac{I_{total}}{W_f}$

$= \frac{30{,}000\ lb \cdot s}{.200\ lb}$

$I_{sp} = 150\ lb \cdot s/lb$

3. (a) $F = (\frac{\Delta m}{\Delta t})(c)$

$F = (\frac{250\ lb}{s})(\frac{1\ slug}{32\ lb})(5000\ ft/s) = 39{,}063\ lb$

(b) $\text{Duration of Burn} = \frac{\text{weight of fuel}}{\text{weight ejected per second}}$

$\text{Duration} = \frac{6000\ lb}{250\ lb/s} = 24\ s$

(c) $I_{total} = F\Delta t = (mv)_{burnout}$; $\therefore\ v_{burnout} = \frac{F\Delta t}{m_{burnout}}$

$v_{burnout} = \frac{(39{,}063\ lb)(24\ s)}{(6000\ lb)(\frac{1\ lb}{32\ slugs})} = 5000\ ft/s$

4. $I_{total} = (mv)_{burnout}$, $\therefore$ $v_{burnout} = \frac{I_{total}}{m_{burnout}}$

$v_{burnout} = \frac{8 \text{ lb·s}}{(0.25 \text{ lb})(\frac{1 \text{ lb}}{32 \text{ slugs}})}$

$v_{burnout} = 1024$ ft/s

5-0, RESISTANCE

2. (a) $F_{vert} = (15 \text{ lb})(\cos 20°) = 14.1$ lb

$F_{hor} = (15 \text{ lb})(\sin 20°) = 5.1$ lb

(b) $N = W - F_{vert}$

$N = 60 \text{ lb} - 14.1 \text{ lb} = 45.9$ lb

(c) $F = \mu_k N$, $\therefore$ $\mu_k = \frac{F}{N}$

$\mu_k = \frac{14.1 \text{ lb}}{54.87 \text{ lb}} = 0.26$

3. $F_s = \mu_s N$; $F_k = \mu_k N$; $\therefore$ $\mu_s = \frac{F_s}{N}$, $\mu_k = \frac{F_k}{N}$

$\mu_s = \frac{15 \text{ lb}}{50 \text{ lb}} = 0.3$

$\mu_k = \frac{12.5 \text{ lb}}{50 \text{ lb}} = 0.25$

5. $R_F = \frac{\Delta p}{Q_H}$, $\therefore$ $\Delta p = R_F Q_H$

(a) $R_F = \frac{5 \text{ lb/in}^2}{3 \text{ gal/min}} = 1.67 \frac{\text{lb/in}^2}{\text{gal/min}}$

(b) $\Delta p = (1.67 \frac{\text{lb/in}^2}{\text{gal/min}})(5 \text{ gal/min}) = 8.35 \text{ lb/in}^2$

6. $R_F = \frac{\Delta p}{Q_H}$, $\therefore$ $Q_H = \frac{\Delta p}{R_F}$

$Q_H = \frac{4.5 \text{ lb/in}^2}{1.5 \text{ lb/in}^2/\text{gal/min}}$

$Q_H = 3$ gal/min

7. $V = IR$; $I = \frac{V}{R}$

(a) $V = (10^{-3} \text{ A})(1000 \ \Omega) = 1$ V

(b) $I = \frac{6 \text{ V}}{1000 \ \Omega} = 0.006 \text{ A} = 6$ mA

8. $R = \frac{V}{I}$

$= \frac{110\ V}{0.91\ A}$

$R = 120.9\ \Omega$

9. $R_T = \frac{\Delta T}{Q_H}$, $Q_H = \frac{\Delta T}{R_T}$

(a) $R_T = \frac{(95°F - 35°F)}{2050\ Btu/h} = 0.029\ F°/Btu/h$

(b) $Q_H = \frac{(80°F - 35°F)}{0.029\ \frac{F°}{Btu/h}} = 1552\ Btu/h$

10. (a) $F_f \propto v$; $\therefore F_f = kv$, so $k = \frac{F_f}{v}$

$k = \frac{50\ lb}{25\ mi/h} = 2\ lb/mi/h$

$F_f = (2\ \frac{lb}{mi/h})(75\ mi/h) = 150\ lb$

(b) $F_f \propto v^2$, $\therefore F_f = kv^2$, so $k = \frac{F_f}{v^2}$

$k = \frac{50\ lb}{(25\ mi/h)^2} = 0.08\ \frac{lb}{mi^2/h^2}$

$F_f = (0.08\ \frac{lb}{mi^2/h^2})(75\ mi/h)^2 = 450\ lb$

SM1, STATIC AND SLIDING FRICTION

2. $\mu_s = \frac{f_s}{N}$, so $f_s = \mu_s N$ (see Table 1 for μ_s)

$f_s = (0.50)(150\ lb)$

$f_s = 75\ lb$

3. $f_k = \mu_k N$; $W = Fs$

$f_k = (0.04)(500\ lb) = 20\ lb$

$W = (20\ lb)(1000\ ft) = 20{,}000\ ft \cdot lb$

4. $\mu_k = \frac{f_k}{N}$; $N = mg$

$\mu_k = \frac{20\ N}{(420\ kg)(9.8\ m/s^2)}$

$\mu_k = 0.0049$

5. $f_s = \mu_s N$; $N = W \cos \theta$, $\therefore$ $f_s = \mu_s W \cos \theta$

$f_s = (0.4)(500 \text{ lb})(\cos 15°)$

$f_s = 193.2 \text{ lb}$

6. The sand is in a state of equilibrium if it slides until a 30° angle is reached. The sand's weight on the incline is equal to the force of static friction.

$W \sin 30° = F_s = \mu_s N = \mu_s W \cos 30°$

$W \sin 30° = \mu_s W \cos 30°$

$\mu_s = \frac{\cancel{W} \sin 30°}{\cancel{W} \cos 30°} = 0.577$

5M2, EFFECTS OF LUBRICANTS

No calculations required.

5M3, ROLLING FRICTION

4. $\mu_s = \frac{F_s}{N}$

$\mu_s = \frac{(0.180 \text{ kg})(9.8 \text{ m/s}^2)}{(7.25 \text{ kg})(9.8 \text{ m/s}^2)}$

$\mu_s = 0.025$

5. $\mu_k = \frac{F_k}{N}$

$\mu_k = \frac{(0.095 \text{ kg})(9.8 \text{ m/s}^2)}{(9.68 \text{ kg})(9.8 \text{ m/s}^2)}$

$\mu_k = 0.0098$

5F1, LAMINAR AND TURBULENT FLOW

1. $$N_R = \frac{(6.32) \times (\text{rate of flow in lb/h})}{(\text{pipe diameter in inches})(\text{absolute viscosity in cP})}$$

$$= \frac{(6.32)(2\ \text{gal/min})(60\ \text{min/h})(8.33\ \text{lb/gal})}{(0.5\ \text{in})(1\ \text{cP})}$$

$$N_R = 12{,}635$$

5F2, VISCOSITY

No calculations required.

5F3, FLUID RESISTANCE IN PIPES

4. $$Q = \frac{1176\ d^4}{\eta\ \ell}(\Delta p)\ ; \quad \text{so} \quad \Delta p = \frac{Q(\eta)(\ell)}{(1176)d^4}$$

$$\Delta p = \frac{(2)(1)(10)}{1176\ (0.5)^4}$$

$$\Delta p = 0.272\ \text{lb/in}^2$$

5. $$Q = \frac{1176\ d^4}{\eta\ \ell}(\Delta p)$$

$$= \frac{(1176)(2)^4(18)}{(1000)(8)}$$

$$Q = 42.3\ \text{gal/min}$$

6. $Q = \frac{1176\ d^5\ \Delta p}{n\ \ell}$, $Q_1 = \frac{1176\ (d_1)^5\ \Delta p_1}{(n_1)\ \ell_1} = 32$ gal/min

(a) $\frac{Q_2}{Q_1} = \frac{\frac{1176\ (d_1)^5\ \Delta p_1}{n_1\ (2\ \ell_1)}}{\frac{1176\ (d_1)^5\ \Delta p_1}{(n_1)(\ell_1)}} = \frac{\frac{1}{2\ell_1}}{\frac{1}{\ell_1}} = \frac{1}{2}$

$\frac{Q_2}{Q_1} = \frac{Q_2}{32\ \text{gal/min}} = \frac{1}{2}$, so $Q_2 = (32\ \text{gal/min})(\frac{1}{2}) = 16$ gal/min

(b) $\frac{Q_2}{Q_1} = \frac{(2\ d_1)^5}{(d_1)^5}$ (everything else cancels)

$\frac{Q_2}{32\ \text{gal/min}} = 16$; so $Q_2 = 512$ gal/min

(c) $\frac{Q_2}{Q_1} = \frac{Q_2}{32\ \text{gal/min}} = \frac{\frac{1}{2}\ \Delta p_1}{\Delta p_1} = \frac{1}{2}$; so $Q_2 = 16$ gal/min

(d) $\frac{Q_2}{Q_1} = \frac{Q_2}{32\ \text{gal/min}} = \frac{\frac{1}{4n_1}}{\frac{1}{n_1}} = \frac{1}{4}$; so $Q_2 = 8$ gal/min

5F4, VALVES AND REGULATORS

No calculations required.

5F5, SHOCK ABSORBER

6. $R = \frac{F}{v}$; $v = \frac{d}{t}$, $\therefore$ $R = \frac{F}{(d/t)}$

$$R_c = \frac{20\ \text{lb}}{(2.5\ \text{in}/1.6\ \text{s})} = 12.8\ \frac{\text{lb}}{\text{in/s}}$$

$$R_d = \frac{45\ \text{lb}}{(3.4\ \text{in}/2.6\ \text{s})} = 34.4\ \frac{\text{lb}}{\text{in/s}}$$

5F6, DRAG RESISTANCE TO MOTION THROUGH FLUIDS

3. (a) $F_D = c_D v_f^2$

$$F_D = 5.8 \times 10^{-3}\ \text{lb/(ft/s)}^2 \left[\frac{100\ (5280\ \text{ft})}{3600\ \text{s}}\right]^2 = 1.25 \times 10^{2}\ \text{lb}$$

(b) $R_D = \frac{F_D}{v_F} = \frac{1.25 \times 10^2\ \text{lb}}{100\ (5280\ \text{ft})/3600\ \text{s}} = 8.52 \times 10^{-1}\ \text{lb/(ft/s)}$

4. (a) $F_D = c_D v_F^3$; $c_D = \frac{F_D}{v_F^3}$

$$c_D = \frac{100{,}000\ \text{lb}}{[50\ (5280\ \text{ft})/3600\ \text{s}]^3} = 0.2541\ \text{lb/(ft/s)}^3$$

(b) $R_D = \frac{F_D}{v_F}$

$$R_D = \frac{100{,}000\ \text{lb}}{50\ (5280\ \text{ft})/3600\ \text{s}} = 1364\ \frac{\text{lb}}{\text{ft/s}}$$

5E1, OHM'S LAW

2. $I = \frac{V}{R}$

$$= \frac{110\ \text{V}}{8000\ \Omega}$$

$$I = 1.375 \times 10^{-2}\ \text{A}$$

3. $V = IR$

$$= (5\ \text{A})(28\ \Omega)$$

$$V = 140\ \text{V}$$

4. $R = \frac{V}{I}$

$= \frac{110\ V}{6\ A}$

$R = 18.3\ \Omega$

5. $V = IR$

$= (22\ \Omega)(5\ A)$

$V = 110\ V$

5E2, SERIES AND PARALLEL RESISTORS

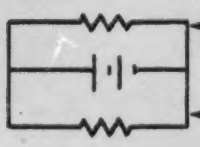
2. Parallel Resistors: $V_T = V_1 = V_2 = V_n$; $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}$

Series Resistors: $R_T = R_1 + R_2 + \ldots R_n$

(a) The voltage across each resistor will be 12 V.

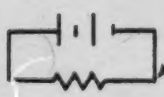
(b) $R = \frac{V}{I}$, for a #1449 bulb $R = \frac{14\ V}{0.2\ A} = 70\ \Omega$

for a #233 bulb $R = \frac{2.33\ V}{0.27\ A} = 8.63\ \Omega$



$R_{1449} = \frac{70\ \Omega}{6} = 11.67\ \Omega$

$R_{233} = 5(8.63\ \Omega) = 43.15\ \Omega$



$\frac{1}{R_T} = \frac{1}{11.67\ \Omega} + \frac{1}{43.15\ \Omega}$ $\therefore$ $R_T = 9.2\ \Omega$

$I_T = \frac{V}{R_T} = \frac{12\ V}{9.2\ \Omega} = 1.3\ A$

3. Series Resistors; $V_T = V_1 + V_2 + \ldots V_n$

(a) $12\ V = V_1 + V_2 + V_3 \ldots V_8 = 8\ (V_{233})$

V_{233} = voltage across each #233 bulb = 1.5 V

(b) $V_T = I_T R_T$; when the number of bulbs in series is increased from five to eight, R_T is increased. Since the emf remains 12 volts, I_T must decrease in order for the above relationship to remain true. Since $I_T = I_1 = I_2 \ldots = I_n$, the current through each bulb is decreased, and the bulbs become less bright.

5E3, INTERNAL RESISTANCE OF A BATTERY

2. $r = (E - V)(\frac{R}{V})$; $R = \frac{V}{I}$

$R = \frac{5\ V}{500\ A} = 0.01\ \Omega$

$r = (12.2\ V - 6.1\ V)(\frac{0.01\ \Omega}{6.1\ V}) = 0.01\ \Omega$

5E4, CONDUCTORS, SEMICONDUCTORS, AND INSULATORS

No calculations required.

5E5, RESISTANCE IN WIRES

1. $R_T = R_{20}\,[1 + \alpha(T-20)]$; $R_{20} = \frac{\rho\ell}{A}$; $1\ mm^2 = 10^{-6}\ m^2$

(a) $R_{20} = \frac{(1.72 \times 10^{-8}\ \Omega\cdot m)(20\ m)}{(8.367 \times 10^{-6}\ m^2)}$

$R_T = R_{20} = 4.1 \times 10^{-2}\ \Omega$

(b) $R_T = \frac{(1.47 \times 10^{-8}\ \Omega\cdot m)(100\ m)}{2.082 \times 10^{-6}\ m^2}\ [1 + 0.00411°C^{-1}\ (135°C - 20°C)]$

$R_T = 1.04\ \Omega$

(c) $R_{20} = \frac{(4.41 \times 10^{-7}\ \Omega\cdot m)(6\ m)}{5.01 \times 10^{-9}\ m^2}$

$R_{20} = 528\ \Omega$

(d) $R_T = \frac{(1.50 \times 10^{-6}\ \Omega\cdot m)(1000\ m)}{5.01 \times 10^{-9}\ m^2}\ [1 + 0.00044°C^{-1}\ (500°C - 20°C)]$

$R_T = 3.63 \times 10^5\ \Omega$

2. $R_{20} = \frac{\rho \ell}{A}$, $A = \frac{\rho \ell}{R_{20}}$

$$A = \frac{(1.72 \times 10^{-8}\ \Omega\cdot m)(10\ m)}{0.84\ \Omega} = 2.048 \times 10^{-7}\ m^2 = 0.2048\ mm^2$$

$A = 0.2048\ mm^2$ corresponds to #24 wire

3. $R_T = R_{20}[1 + \alpha(T - 20)]$; $T = \frac{R_T - R_{20} + 20 R_{20} \alpha}{R_{20} \alpha}$

$$T = \frac{8.0\ \Omega - 2.63\ \Omega + 20(2.63\ \Omega)(0.0049°C^{-1})}{2.63\ \Omega(0.0049°C^{-1})}$$

$T = 437°C$

4. $R_{20} = \frac{\rho \ell}{A}$ $\rho = \frac{R_{20} A}{\ell}$

$$\rho = \frac{(0.858\ \Omega)(1.288 \times 10^{-7}\ m^2)}{4.2\ m} = 2.63 \times 10^{-8}\ \Omega\cdot m$$

resistivity of aluminum

5. $R_{88} = R_{26}[1 + \alpha(88°C - 26°C)]$; $\alpha = \frac{R_{88} - R_{26}}{R_{26}(88°C - 26°C)}$

$$\alpha = \frac{180\ \Omega - 133\ \Omega}{138\ \Omega(88°C - 26°C)} = 0.0049°C^{-1}$$

α for tungsten

5E6, RESISTANCE OF SEMICONDUCTOR JUNCTIONS

No calculations required.

5E7, RESISTANCE OF GAS LASER TUBES

5. $R_B = \frac{V - V_t}{I}$

$R_B = \frac{2500\ V - 1353\ V}{3.5 \times 10^{-3}\ A}$

$R_B = 3.28 \times 10^5\ \Omega$

6. $V_b = 3350\ V$

$V_s = 1275\ V$

5E8, VOLT-OHM MILLIAMMETER

No calculations required.

5T1, THERMAL CONDUCTIVITY

2. $H = \frac{kA\ (T_2 - T_1)}{x}$, $\therefore\ T_2 = \frac{H(x) + (k)(A)(T_1)}{kA}$

$T_2 = \frac{(700\ Btu/h)(0.75\ in) + (0.80\ Btu \times in/hr \times ft^2 \cdot F^\circ)(8\ ft \times 12\ ft)(72^\circ F)}{(0.80\ Btu \times in/h \times ft^2 \cdot F^\circ)(8\ ft \times 12\ ft)}$

$T_2 = 78.84^\circ F$

3. $H = \frac{kA\ (T_2 - T_1)}{x}$, $\therefore\ x = \frac{kA\ (T_2 - T_1)}{H}$

$x = \frac{(0.25\ Btu \times in/h \times ft^2 \cdot F^\circ)(1\ ft^2)(50\ F^\circ)}{5\ Btu/h}$

$x = 2.5\ in$

5T2, HEAT FLOW THROUGH INSULATION

3. $R_T = R_1 + R_2 + \ldots + R_n$; $U = \frac{1}{R_T}$

$R_T = 0.68 + 0.39 + 12.00 + 0.10 + 1.0 + 0.17 = 14.34$

$U = \frac{1}{14.34} = 0.0697$

3. $P = \frac{Fd}{t}$; 1 hp = 550 ft·lb/s

$$P = \frac{(250\ \text{lb})(200\ \text{ft})}{120\ \text{s}} \left(\frac{1\ \text{hp}}{550\ \text{ft·lb/s}}\right)$$

$$P = 0.76\ \text{hp}$$

4. $P = \tau\omega$, $\tau = \frac{P}{\omega}$

$$\tau = \frac{(50\ \text{hp})(\frac{550\ \text{ft·lb/s}}{\text{hp}})}{(2000\ \frac{\text{rev}}{\text{min}})(\frac{2\pi\ \text{rad}}{\text{rev}})(\frac{1\ \text{min}}{60\ \text{s}})}$$

$$\tau = 131.3\ \text{ft·lb}$$

5. $\eta = \frac{P_{out}}{P_{in}}(100)$, 1 hp = 746 W ; $P = \Delta\rho(\frac{\Delta v}{\Delta t})$, $\Delta\rho = \rho_w h$, so $\Delta t = \frac{(\rho_w h)(\Delta v)}{P}$

$$\eta = \frac{(5\ \text{hp})(\frac{746\ \text{W}}{\text{hp}})}{5000\ \text{W}} \times 100 = 74.6\%$$

$$\Delta t = \frac{(62.4\ \text{lb/ft}^3)(46\ \text{ft})(2500\ \text{ft}^3)}{5\ \text{hp}\ (\frac{550\ \text{ft·lb/s}}{\text{hp}})} = 2609\ \text{s}\ \ (43\ \text{min},\ 30\ \text{s})$$

6. $\eta = \frac{P_{out}}{P_{in}}(100)$; $P_{out} = \tau\omega$, $P_{in} = IV$, $\therefore\ \eta = \frac{\tau\omega}{IV}(100)$

$$\eta = \frac{(42\ \text{ft·lb})\ (250\ \frac{\text{rev}}{\text{min}})(\frac{2\pi\ \text{rad}}{\text{rev}})(\frac{1\ \text{min}}{60\ \text{s}})}{(7.5\ \text{A})(240\ \text{V})(\frac{1\ \text{ft·lb/s}}{1.356\ \text{W}})}\ \ (100)$$

$$\eta = 82.8\%$$

7. $P = I^2R$; $P = \frac{W}{t}$, $W = P{\cdot}t$, $\therefore\ W = I^2R\ (t)$, $\quad (1\ \text{Watt} = \frac{1\ \text{J}}{\text{s}})$

$$W = (10\ \text{A})^2(2\ \Omega)(60\ \text{s})(\frac{1\ \text{cal}}{4.186\ \text{J}})$$

$$W = 2866.7\ \text{cal}$$

8. $$746\ \text{W} = (1\ \text{hp})(\frac{550\ \text{ft·lb/s}}{\text{hp}})(\frac{3600\text{s}}{\text{h}})(\frac{1\ \text{Btu}}{778\ \text{ft·lb}})$$

$$746\ \text{W} = 2545\ \text{Btu/h}$$

$$1\ \text{W} = 3.41\ \text{Btu/h}$$

2. $1\ \text{hp} = 550\ \text{ft·lb/s}\ ;\ P = \frac{Fd}{t}$

$$P = \frac{850\ \text{lb}\ (240\ \text{ft})}{15\ (60\ \text{s})} = 226.7\ \frac{\text{ft·lb}}{\text{s}}$$

$$P = 226.7\ \frac{\text{ft·lb}}{\text{s}}\left(\frac{1\ \text{hp}}{550\ \frac{\text{ft·lb}}{\text{s}}}\right) = 0.412\ \text{hp}$$

3. $P = \frac{Fd}{t}$

$$= \frac{180\ \text{lb}\ (36\ \text{ft})}{18\ \text{s}} = 360\ \frac{\text{ft·lb}}{\text{s}}$$

$$P = 360\ \frac{\text{ft·lb}}{\text{s}}\left(\frac{1\ \text{hp}}{550\ \frac{\text{ft·lb}}{\text{s}}}\right) = 0.655\ \text{hp}$$

4. $P = \frac{Fd}{t}$

$$= \frac{(250\ \text{lb})(3\ \text{ft})}{(0.5\ \text{s})} = 1500\ \frac{\text{ft·lb}}{\text{s}}$$

$$P = 1500\ \frac{\text{ft·lb}}{\text{s}}\left(\frac{1\ \text{hp}}{550\ \frac{\text{ft·lb}}{\text{s}}}\right) = 2.73\ \text{hp}$$

5. $d = \frac{1}{2}at^2\ ;\ P = \frac{Fd}{t}\ ;\ F = ma\ ;\quad P = \frac{mad}{t}\ ;\ 1\ \text{hp} = 746\ \text{W}$

$$d = \tfrac{1}{2}(16\ \text{m/s}^2)(10\ \text{s})^2 = 800\ \text{m}$$

$$P = \frac{(820\ \text{kg})(16\ \text{m/s}^2)(800\ \text{m})}{10\ \text{s}}\ \frac{1\ \text{hp}}{746\ \text{W}} = 1407\ \text{hp}$$

6. $a = \frac{v_2^2 - v_1^2}{2s}\ ;\ P = \frac{mad}{t}\ ;\ 185\ \text{mph} = 271.3\ \text{ft/s}\ ;\ t = \sqrt{\frac{2d}{a}}\ ;\ m = \frac{\text{wt (lb)}}{32\ \text{ft/s}^2}$

$$a = \frac{(271.3\ \text{ft/s})^2 - (0)^2}{2(0.25)(5280\ \text{ft})} = 27.9\ \text{ft/s}^2\ ;\ t = \left(\frac{2(0.25)(5280)\ \text{ft}}{27.9\ \text{ft/s}}\right)^{\frac{1}{2}} = 9.73\ \text{s}$$

$$P = \frac{(\frac{1850\ \text{lb}}{32\ \text{ft/s}^2})(27.9\ \text{ft/s}^2)(0.25)(5280\ \text{ft})}{9.73\ \text{s}}\left(\frac{1\ \text{hp}}{550\ \frac{\text{ft·lb}}{\text{s}}}\right) = 398\ \text{hp}$$

7. $1\ \text{hp} = 550\ \frac{\text{ft·lb}}{\text{s}}\ ;\ P = \frac{Fd}{d}\quad \text{so } t = \frac{Fd}{P}$

$$25\ \text{hp} = (25\ \text{hp})\ (550\ \tfrac{\text{ft·lb}}{\text{s}}) = 13{,}750\ \frac{\text{ft·lb}}{\text{s}}$$

$$t = \frac{Fd}{P} = \frac{(8000\ \text{lb})(22\ \text{ft})}{13{,}750\ \frac{\text{ft·lb}}{\text{s}}} = 12.8\ \text{s}$$

8. $P = \frac{Fd}{t}\quad \text{so } t = \frac{Fd}{P} = \frac{mad}{P}\quad \text{where } a = \frac{v_f}{t}\ ;\ d = \bar{v}t\ ;\ \bar{v} = \frac{v_i + v_f}{2}$

$$\therefore\ t = \frac{mad}{P} = \frac{m(\frac{v_f}{t})(\bar{v}t)}{P} = \frac{m\,v_f\,\bar{v}}{P}$$

$$t = \frac{(\frac{3200}{32})(88\ \text{ft/s})(44\ \text{ft/s})}{72\ \text{hp} \times \frac{550\ \frac{\text{ft·lb}}{\text{s}}}{1\ \text{hp}}} = 9.78\ \text{s}$$

6M2, PRONY BRAKE

4. $\tau = F\ell$; $P(hp) = \frac{\tau\ (ft \cdot lb)\ \omega\ (rev/min)}{5252}$

$\tau = (20\ oz)(\frac{1\ lb}{16\ oz})(3\ ft) = 3.75\ ft \cdot lb$

$P = \frac{(3.75)(1200\ rev/min)}{5252} = 0.857\ hp$

5. $\eta = \frac{P_{out}}{P_{in}}(100)$; $P_{in} = IV$

$\eta = \frac{0.857\ hp\ (100)}{(6.75\ A)(110\ V)(\frac{1\ hp}{746\ W})}$

$\eta = 86.1\%$

6F1, HYDRAULIC POWER

3. $\Delta p = 0.433\ (S_g)(\Delta h)$

$\Delta p = 0.433\ (.85)(25) = 9.2\ psi$

If the tank is open to the atmosphere, the total pressure is 9.2 psi + the pressure due to the atmosphere (14.7 psi) = 23.9 psi.

4. $P = \frac{(S_g)\ Q\ h}{3963}$

$= \frac{(1)(50)(15)}{3963}$

$P = 0.189\ hp$

6E1, ELECTRICAL POWER MEASUREMENT

6. 2000 kWh (0.00138) = 2.76 kWh = use factor

Total # of kWh + use factor = 2002.76 kWh

Fixed cost	= $ 2.75
(200 kWh)($0.0435/kWh	= $ 8.70
(1300 kWh)($0.0314/kWh)	= $ 40.82
(502.76 kWh)($0.0287/kWh)	= $ 14.43
	$ 66.70
4% tax + (0.04)(66.70)	= $ 2.67
Total Cost	= $ 69.37

7. Total of kWh used = 2000 kWh - 786 kWh = 1214 kWh

1214 kwn + (0.00138)(1214 kWh) = 1215.68 kWh

Fixed cost	= $ 2.75
(200 kWh)($0.0435/kWh)	= $ 8.70
(1015.68 kWh)($0.0314/kWh)	= $ 31.89
	$ 43.34
4% tax + (0.04)($43.34)	= $ 1.73
Total Cost	= $ 45.07

Cost Savings = $69.37 - $45.07 = $24.30

6E2, ELECTRIC HEATER

3. (a) $P = IV$, so $I = \frac{P}{V}$

$$I = \frac{800\ W}{115\ V} = 6.96\ A$$

(b) $P = I^2R$, so $R = \frac{P}{I^2}$

$$R = \frac{800\ W}{(6.96\ A)^2} = 16.5\ \Omega$$

(c) $P = \frac{mc\Delta T}{t}$, so $t = \frac{mc\Delta T}{P}$

$$t = \frac{(1.5\ \ell)(\frac{1000\ cm^3}{\ell})(\frac{1\ g}{cm^3})(1\ cal/g\ C°)(100°C - 15°C)}{(800\ \frac{J}{s})(\frac{1\ cal}{4.184\ J})} = 667\ s$$

4. $P = IV$

$= (6.4\ A)(115\ V)$

$P = 736\ W$

5. $P = \frac{V^2}{R}$, so $R = \frac{V^2}{P}$

$R = \frac{(208\ V)^2}{2000\ W}$

$R = 21.6\ \Omega$

6. $P_1 = \frac{V_1^2}{R_1}$ $\quad P_2 = \frac{(2\ V_1)^2}{R_1}$

$\frac{P_2}{P_1} = \frac{\frac{(2V_1)^2}{R_1}}{\frac{(V_1)^2}{R_1}} = 4$,

Power dissipated in a resistor is quadrupled when the applied voltage is doubled.

6E3, EFFICIENCY OF ELECTRIC MOTORS AND GENERATORS

6. $\eta = \frac{P_{out}}{P_{in}}(100)$; $P_{out} = \tau\omega$; $P_{in} = IV$

$P_{in} = (14\ A)(12\ V) = 168\ W$; $P_{out} = (0.86\ ft\cdot lb)(1200\ \frac{rev}{min})(\frac{2\pi\ rad}{rev})(\frac{1\ min}{60\ s}) = 108.1\ \frac{ft\cdot lb}{s}$

$$\eta = \frac{(108.1\ \frac{ft\cdot lb}{s})\left(\frac{1\ hp}{550\ \frac{ft\cdot lb}{s}}\right)(\frac{746\ W}{1\ hp})}{168\ W}(100) = \frac{146.6}{168}(100) = 87\%$$

7. $\eta = \frac{P_{out}}{P_{in}}(100)$ so $P_{out} = \frac{\eta(P_{in})}{100}$; $P_{out} = IV$

$$I\ (125\ V) = \frac{88\ (250\ hp)(\frac{746\ W}{hp})}{100}$$

$I = 1313\ A$

6E4, ELECTRICAL POWER CONSUMPTION

1. $P = I\ V\ PF$; $I = \frac{P}{V(PF)}$

$$I = \frac{1500\ W}{(120\ V)(1)}$$

$I = 12.5\ A$

2. $P = I\ V\ PF$; $I = \frac{P}{V(PF)}$; $1\ hp = 745.7\ W$

$$I = \frac{745.7\ W}{120\ V(0.6)}$$

$I = 10.4\ A$

3. $E = Pt$; $C = ER$

(a) $E = 1.2\ kW\ (36\ h) = 43.2\ kWh$

$C = (43.2\ kWh)(3¢/kWh)$

$C = 129.6¢ \approx \$1.30$

(b) $E = (0.746\ kW)(1000\ h) = 746\ kWh$

$C = (746\ kWh)(3¢/kWh)$

$C = 2238¢ \approx \$22.38$

2. $P = (T_1 - T_2)(\frac{\Delta V}{t})(c)$

$= (52°C - 31°C)(\frac{7.62 \times 10^3\ g}{60\ s})(1\ cal/g·C°)$

$P = (2667\ cal/s)(4.1861\ J/cal) = 1.12 \times 10^4\ W$

3. $P = (T_1 - T_2)(\frac{\Delta V}{t})(c)$; $T_1 = \frac{P + T_2\ (\frac{\Delta V}{t})(c)}{(\frac{\Delta V}{t})(c)}$

$$T_1 = \frac{6500\ W + (27.6°C)(\frac{6.3 \times 10^3\ g}{60\ s})(\frac{1\ cal}{g·C°})(\frac{4.186\ J}{cal})}{(\frac{6.3 \times 10^3\ g}{60\ g})(\frac{1\ cal}{g·C°})(\frac{4.186\ J}{cal})}$$

$T_1 = 42.4°C$

4. $P = (T_1 - T_2)(\frac{\Delta V}{t})(c)$, so $\frac{\Delta V}{t} = \frac{P}{(T_1 - T_2)(c)}$

$$\frac{\Delta V}{t} = \frac{1000\ W}{(25°C - 24°C)(\frac{1\ cal}{g·C°})(\frac{4.186\ J}{cal})}$$

$\frac{\Delta V}{t} = (238.9\ g/s)(\frac{1\ \ell}{10^3\ g})(\frac{60\ s}{min}) = 14.3\ \ell/min$

7-O, POTENTIAL AND KINETIC ENERGY

2. $E_K = \frac{1}{2} mv^2$

$= \frac{1}{2} (2800 \text{ lb})(\frac{1 \text{ kg}}{2.205 \text{ lb}}) \left[(55 \text{ mi/h})(\frac{1609 \text{ m}}{\text{mi}})(\frac{1 \text{ h}}{3600 \text{ s}})\right]^2$

$E_K = 383{,}665 \text{ J} = 284{,}686 \text{ ft·lb}$

3. $E_K = \frac{1}{2} mv^2$, so $v = \sqrt{\frac{2 E_K}{m}}$

$v = \sqrt{\frac{2 (2)(383{,}665) \text{ J}}{(2800 \text{ lb})(\frac{1 \text{ kg}}{2.205 \text{ lb}})}}$

$v = 34.7 \text{ m/s} = 77.8 \text{ mi/h}$ (velocity increased by a factor of $\sqrt{2}$)

4. $E_p = mgh$

$= (1800 \text{ lb})(70 \text{ ft})$

$E_p = 126{,}000 \text{ ft·lb}$

5. $E_p = \frac{1}{2} kx^2$; so $k = \frac{2 E_p}{x^2}$

$k = \frac{2 (25 \text{ N})}{(0.15 \text{ m})^2} = 2222 \text{ N/m}^2$

$E_p = \frac{1}{2} (2222 \text{ N/m}^2)(0.45 \text{ m})^2 = 225 \text{ N·m}$

6. $E_p = \frac{1}{2} CV^2$

$= (\frac{1}{2})(1.5 \times 10^{-6} \text{ F})(6.0 \text{ V})^2$

$E_p = 2.7 \times 10^{-5} \text{ J}$

7. $E_K = (\frac{1}{2}) mv^2 + (\frac{1}{2}) I\omega^2$; $\omega = \frac{v}{r}$; $I = \frac{1}{2} mr^2$

$E_K = \frac{1}{2} (5 \text{ kg})(20 \text{ m/s})^2 + \frac{1}{2} (\frac{1}{2})(5 \text{ kg})(r^2) \frac{(20 \text{ m/s})^2}{r^2}$

$E_K = 1500 \text{ J}$

8. $p_a + \frac{1}{2} \rho v_a^2 + \rho g h_a = p_b + \frac{1}{2} \rho v_b^2 + \rho g h_b$

$v_a = 0$; $h_b = 0$; $p_a = p_b$

$p_a + \rho g h_a = p_b + \frac{1}{2} \rho v_b^2$

$\rho g h_a = \frac{1}{2} \rho v_b^2$

$v_b = \sqrt{2 g h_a}$

$v_b = \sqrt{2 (32 \text{ ft/s}^2)(50 \text{ ft})}$

$v_b = 56.6 \text{ ft/s}$

7M1, PILEDRIVER

1. $PE = mGh$, $w = mg$

   (a) $PE = (100\ kg)(9.8\ m/s^2)(2\ m) = 1960\ N \cdot m$

   (b) $PE = (50{,}000\ lb)(4\ ft) = 200{,}000\ ft \cdot lb$

   (c) $PE = (2850\ kg)(9.8\ m/s^2)(16.8\ m) = 469{,}000\ N \cdot m$

   (d) $PE = (2100\ lb)(35\ ft) = 73{,}500\ ft \cdot lb$

2. $v = \sqrt{2\ Gh}$

   (a) $v = \sqrt{2\ (9.8\ m/s^2)(2\ m)} = 6.26\ m/s$

   (b) $v = \sqrt{2\ (32\ ft/s^2)(4\ ft)} = 16\ ft/s$

   (c) $v = \sqrt{2\ (9.8\ m/s^2)(16.8\ m)} = 18.15\ m/s$

   (d) $v = \sqrt{2\ (32\ ft/s^2)(35\ ft)} = 47.33\ ft/s$

3. $KE = (\frac{1}{2})\ mv^2$

   (a) $KE = \frac{1}{2}\ (100\ kg)(6.26\ m/s)^2 = 1960\ J$

   (b) $KE = \frac{1}{2}\ (50{,}000\ lb)(\frac{1\ slug}{32\ lb})(16\ ft/s)^2 = 200{,}000\ ft \cdot lb$

   (c) $KE = \frac{1}{2}\ (2850\ kg)(18.15\ m/s)^2 = 469{,}000\ J$

   (d) $KE = \frac{1}{2}\ (2100\ lb)(\frac{1\ slug}{32\ lb})(47.33\ ft/s)^2 = 73{,}500\ ft \cdot lb$

7M2, POTENTIAL AND KINETIC ENERGY OF A SPRING

2. $E_p = \frac{1}{2}\ kx^2$, $k = -\frac{F}{x}$, so $E_p = \frac{1}{2}\ (\frac{F}{x})\ x^2 = \frac{1}{2}\ Fx$

   $E_p = \frac{1}{2}\ (30\ N)(0.03\ m)$

   $E_p = 0.45\ J$

3. (a) $F = -\ kx$, $F = -\ mg$; so $m = \frac{kx}{g}$

   $m = \frac{(50\ N/m)(0.042\ m)}{9.8\ m/s^2} = 0.214\ kg$

   (b) $E_p = \frac{1}{2}\ kx^2$

   $E_p = \frac{1}{2}\ (50\ N/m)(0.042\ m)^2 = 0.044\ J$

4. (a) $K = -\frac{F}{x}$

$K = -\left(\frac{500\ lb}{-4\ in}\right)\left(\frac{12\ in}{1\ ft}\right) = 1500\ lb/ft$

(b) $E_p = \frac{1}{2} kx^2$

$E_p = \frac{1}{2}(1500\ lb/ft)(1/3\ ft)^2 = 83.3\ ft \cdot lb$

(c) $T = 2\pi\sqrt{\frac{m}{k}}$

$T = 2\pi\sqrt{\frac{(500\ lb)\left(\frac{1\ slug}{32\ lb}\right)}{1500\ lb/ft}} = 0.64\ s$

5. (a) $F = -kx$, $F = -(500\ lb + Wa)$; so $Wa = -kx - 500\ lb$

$Wa = -(1500\ lb/ft)(-8/12\ ft) - 500\ lb = 500\ lb$

(b) $E_p = \frac{1}{2} kx^2$

$E_p = \frac{1}{2}(1500\ lb/ft)(8/12\ ft)^2 = 333\ ft \cdot lb$

(c) $T = 2\pi\sqrt{\frac{m}{k}}$

$T = 2\pi\sqrt{\frac{1000\ lb\ \left(\frac{1\ slug}{32\ lb}\right)}{1500\ lb/ft}} = 0.907\ s$

7M3, ROTATIONAL KINETIC ENERGY OF A FLYWHEEL

1. $I = \frac{1}{2} mr^2$

$= \frac{1}{2}(4.7\ kg)(0.35\ m)^2$

$I = 0.288\ kg \cdot m^2$

2. $E_K = \frac{1}{2} I\omega^2$; $I = mr^2$

$= \frac{1}{2}(2.2\ kg)(0.85\ m)^2(50\ rad/s)^2$

$E_K = 1987\ J$

3. $E_K = \frac{1}{2} I\omega^2$; $I = \frac{1}{2} mr^2$

$5000\ \frac{rev}{min}\left(\frac{2\pi\ rad}{rev}\right)\left(\frac{1\ min}{60\ s}\right) = 523.6\ rad/s$

$E_K = \left(\frac{1}{2}\right)\left(\frac{1}{2}\right)(400\ kg)(0.30\ m)^2(523.6\ rad/s)^2 = 2.47 \times 10^6\ J$

4. $E_K = \frac{1}{2} I\omega^2$; $\omega = \sqrt{\frac{2 E_K}{I}}$

$\omega = \sqrt{\frac{2(10^5 \text{ J})}{0.032 \text{ kg}\cdot\text{m}^2}}$

$\omega = 791 \text{ rad/s} = 7550 \text{ rev/min}$

5. $E_K = \frac{1}{2} I\omega^2$; $\omega = \sqrt{\frac{2 E_K}{I}}$

$\omega = \sqrt{\frac{2(2 \times 10^6 \text{ J})}{0.032 \text{ kg}\cdot\text{m}^2}}$

$\omega = 1.12 \times 10^5 \text{ rad/s} = 1.07 \times 10^5 \text{ rev/min}$

7M4, CONSERVATION OF ENERGY IN COLLISIONS

3. $E_{K_1} = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$; $E_{K_2} = \frac{1}{2} (m_1 + m_2) v_f^2$;

$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$; $E = E_{K_1} - E_{K_2}$

$(1000 \text{ kg})(10 \text{ m/s}) + (1250 \text{ kg})(-8 \text{ m/s}) = 0 = (1000 \text{ kg} + 1250 \text{ kg}) v_f$

$v_f = 0$

$E = E_{K_1} - E_{K_2} = \frac{1}{2}(1000 \text{ kg})(10 \text{ m/s})^2 + \frac{1}{2} (1250 \text{ kg})(-8 \text{ m/s})^2 - \frac{1}{2} (1000 \text{ kg} + 1250 \text{ kg})(0 \text{ m/s})$

$E = E_{K_1} - 0 = 90{,}000 \text{ J}$

4. (a) $v_1 = \left(\frac{m_1 + m_2}{m_1}\right) \sqrt{2 gh}$

$v_1 = \left(\frac{0.009 \text{ kg} + 2 \text{ kg}}{0.009 \text{ kg}}\right) \sqrt{2(9.8 \text{ m/s}^2)(0.032 \text{ m})} = 176.8 \text{ m/s}$

(b) $E_K = \frac{1}{2} mv^2 = \frac{1}{2}(0.009 \text{ kg})(176.8 \text{ m/s})^2 = 141 \text{ J}$

(c) $v_2 = \sqrt{2gh}$

$v_2 = \sqrt{2(9.8 \text{ m/s}^2)(0.032 \text{ m})} = 0.79 \text{ m/s}^2$

(d) $E = E_{K_1} - E_{K_2} = m_1 v_1 - (m_1 + m_2) v_2$

$= (0.009 \text{ kg})(176.8 \text{ m/s}) - (0.009 \text{ kg} + 2 \text{ kg})(0.79 \text{ m/s}^2)$

$E = 4.1 \times 10^{-3} \text{ J}$

5. Assume that 246 bhp is the average hp.

$$P = (198\ \frac{hp \cdot s^3}{lb})(\frac{W}{t^3}) \quad ; \quad t^3 = \frac{\left(198\ \frac{hp \cdot s^3}{lb}\right) W}{P}$$

$$t^3 = \frac{(198\ \frac{hp \cdot s^3}{lb})(2500\ lb)}{246\ hp} = 2012.2\ s^3$$

$$t = 12.62\ s$$

6. $$P = (198\ \frac{hp \cdot s^3}{lb})(\frac{W}{t^3}) \quad ; \quad t^3 = \frac{(198\ \frac{hp \cdot s^3}{lb})\ W}{P}$$

$$P = P_o + 0.2\ P_o = 130\ hp + 0.2\ (130\ hp) = 156\ hp$$

$$t^3 = \frac{(198\ \frac{hp \cdot s^3}{lb})(1560\ lb)}{156\ hp} = 1980\ s^3$$

$$t = 12.56\ s$$

7. $$P = (198\ \frac{hp \cdot s^3}{lb})(\frac{W}{t^3})$$

$$= (198\ \frac{hp \cdot s^3}{lb})\ \frac{1980\ lb}{(19.08\ s)^3}$$

$$P = 56.44\ hp$$

5. $v = \sqrt{2\,Gh}$; Vol. flow rate = (cross sectional area)(velocity)

$v = \sqrt{2(9.8\ m/s^2)(30\ m)} = 24.25\ m/s$

Vol. flow rate $= \pi\left(\frac{0.1\ m}{2}\right)^2(24.25\ m/s)\left(\frac{3600\ s}{h}\right)$

Vol. flow rate = 685.7 m^3/h

6. (a) $v = \sqrt{2\,Gh}$

$v = \sqrt{2(9.8\ m/s^2)(1\ m)} = 4.43\ m/s$

(b) Mass flow rate = (cross sectional area)(velocity)(density of fluid)

Mass flow rate $= (1\ cm^2)\left(\frac{1\ m}{100\ cm}\right)^2(4.43\ m/s)(1000\ kg/m^3)$

Mass flow rate = 0.443 kg/s

7. $H = \frac{1}{2}\,Gt^2$; $x = (V_{outlet})(t)$

$t = \sqrt{\frac{2H}{G}}$

$x = (V_{outlet})\left(\sqrt{\frac{2H}{G}}\right)$

$V_{outlet} = \left(\sqrt{\frac{G}{2H}}\right)(x) = \left(\sqrt{\frac{9.8\ m/s^2}{2\ (0.306\ m)}}\right)(x) = 4\ x\ m/s$

7F2, VENTURI METERS

3. $v_1 = \sqrt{2\left(\frac{\rho_M - \rho_F}{\rho_F}\right)\left(\frac{A_2^2}{A_1^2 - A_2^2}\right) gh}$; Vol. flow rate = $v_1 (A_1)$

Vol. flow rate = $\frac{\pi (15\ cm)^2}{4} \sqrt{2\left(\frac{13.6\ g/cm^3 - 1\ g/cm^3}{13.6\ g/cm^3}\right)\left[\frac{(7\ cm)^2}{(15\ cm)^2 - (7\ cm)^2}\right]} * (980\ \frac{cm}{s^2})(17.5\ cm)$

Vol. flow rate = 16,622 cm^3/s

*In the equation for v_1 diameters have been used in place of areas since all other factors for area cancel out of the equation.

4. $A_1v_1 = A_2v_2$; $p_1 - p_2 = \frac{1}{2}\rho v_2^2 - \frac{1}{2}\rho v_1^2$

(a) $v_2 = \frac{A_1v_1}{A_2} = \frac{(8.0\ in^2)(6.0\ ft/s)}{1\ in^2} = 24\ ft/s$

(b) $p_2 = p_1 - \frac{1}{2}\rho v_2^2 + \frac{1}{2}\rho v_1^2$; $42\ lb/ft^3 \equiv 1.313\ slugs/ft^3$

$p_2 = (10\ lb/in^2)(\frac{144\ in^2}{ft^2}) - \frac{1}{2}(1.313\ slug/ft^3)(24\ ft/s)^2 + \frac{1}{2}(1.313\ slugs/ft^3)(6\ ft/s)^2$

$p_2 = 1085\ lb/ft^2 = 7.54\ lb/in^2$

7F3, PITOT TUBES

3. $v_D = \sqrt{2\ g\ (\frac{\rho_L}{\rho_F})\ h}$

$= \sqrt{2\ (32\ ft/s^2)(\frac{62.4\ lb/ft^3}{0.075\ lb/ft^3})(0.20\ in)(\frac{1\ ft}{12\ in})}$

$v_D = 29.8\ ft/s$

4. $v_D = \sqrt{2\ g\ (\frac{\rho_L}{\rho_F})\ h}$; $\frac{\rho_L}{\rho_F} = \frac{62.4\ lb/ft^3}{0.075\ lb/ft^3} = 832$

(a) $h = 3.04\ in$; $v_D = \sqrt{2(32\ ft/s^2)(832)(3.04\ in)(\frac{1\ ft}{12\ in})} = 116\ ft/s$

(b) $h = 6.92\ in$; $v_D = \sqrt{2(32\ ft/s^2)(832)(6.92\ in)(\frac{1\ ft}{12\ in})} = 175\ ft/s$

(c) $h = 9.63\ in$; $v_D = \sqrt{2(32\ ft/s^2)(832)(9.63\ in)(\frac{1\ ft}{12\ in})} = 207\ ft/s$

(d) $h = 14.00\ in$; $v_D = \sqrt{2(32\ ft/s^2)(832)(14.00\ in)(\frac{1\ ft}{12\ in})} = 249\ ft/s$

These theoretical velocities would not be achieved in actual measurements because air temperature and pressure altitude were not considered.

7F4, ENERGY CONVERSIONS IN FLUID SYSTEMS

2. $PE = wh$; $w = V\rho_w$, From Ex: A, $\rho_w = 8.337$ lb/gal

$PE = (50{,}000 \text{ gal})(8.337 \text{ lb/gal})(50 \text{ ft})$

$PE = 2.1 \times 10^7$ ft·lb

3. $KE = \text{vol} \times P$; 1 gal = 231 in^3

$KE = (1000 \text{ gal})\left(\frac{231 \text{ in}^3}{\text{gal}}\right)(80 \text{ lb/in}^2)\left(\frac{1 \text{ ft}}{12 \text{ in}}\right)$

$KE = 1.54 \times 10^6$ ft·lb

4. $P = hd$

$= (30 \text{ ft})(62.4 \text{ lb/ft}^3)$

$P = 1872 \text{ lb/ft}^2 = (1872 \text{ lb/ft}^2)\left(\frac{1 \text{ ft}^2}{144 \text{ in}^2}\right) = 13 \text{ lb/in}^2$

7F5, GAS LAWS

5. $\frac{p_1}{T_1} = \frac{p_2}{T_2}$, $p_2 = \frac{p_1}{T_1}(T_2)$

$p_2 = (28 + 14.7) \text{ psia} \left[\frac{(110 + 460)^\circ R}{(-30 + 460)^\circ R}\right]$

$p_2 = 566 \text{ psia} = 41.9 \text{ psig}$

2. $\Delta p = \rho g\ (\Delta h)$

$= (62.4\ lb/ft^3)(136\ ft)$

$\Delta p = 8486.4\ lb/ft^2$

3. $v = \sqrt{2\ g\Delta h}$

$= \sqrt{2\ (32\ ft/s^2)(136\ ft)}$

$v = 93.3\ ft/s$

4. If the water level in the upper container drops, then v_1 is no longer zero. The resulting equation is then;

$\frac{1}{2}\ \rho v_2^2 = \rho g(\Delta h) + \frac{1}{2}\ \rho v_1^2$

$v_2 = \sqrt{2\ g(\Delta h) + v_1^2}$ (v_2 is increased)

6. $F = \rho g \Delta h - \frac{1}{2}\ \rho v_2^2$; $v = \frac{Q_V}{A}$; $A = \pi r^2$

$v = \frac{5\ ft^3/s}{\pi\ (0.25\ ft)^2} = 25.5\ ft/s$

$F = (42.4\ lb/ft^3)(25\ ft) - \frac{1}{2}\ (\frac{42.4\ lb/ft^3}{32\ ft/s^2})(25.5\ ft/s)^2 = 629.2\ lb/ft^2$

7. $F_2 = (1 - 0.25)\ F_1$; $F_2 = \rho g \Delta h - \frac{1}{2}\ \rho v_2^2$; $v_2 = \sqrt{2\ g\Delta h - 2\ F_2/\rho}$

$v_2 = \sqrt{2\ (32\ ft/s^2)(25\ ft) - \frac{2\ (0.75)(629.2\ lb/ft^2)}{(42.4\ lb/ft^3\ /32\ ft/s^2)}} = 29.8\ ft/s$

$Q_V = v_2 A = (29.8\ ft/s)(\pi)(0.25\ ft)^2 = 5.85\ ft^3/s$

7E1, ENERGY STORED IN A BATTERY

5. $Q = It$; $W = VQ$; $E_p = VQ$

(a) $Q = (5\ A)(5\ h)(\frac{3600\ s}{1\ h}) = 90{,}000\ C$

(b) $E_p = (90{,}000\ C)(6.0\ V) = 540{,}000\ J$

(c) $W = (90{,}000\ C)(5.0\ V) = 450{,}000\ J$

(d) $W = (20\ A)(90\ min)(\frac{60\ s}{min})(7.0\ V) = 756{,}000\ V$

7E2, ENERGY STORED IN A CAPACITOR

1. $E_p = \frac{1}{2} CV^2$

$= \frac{1}{2} (2000 \times 10^{-6}\ F)(240\ V)^2$

$E_p = 57.6\ J$

2. $E_p = \frac{1}{2} CV^2$

$= \frac{1}{2} (375 \times 10^{-6}\ F)(4000\ V)^2$

$E_p = 3000\ J$

3. $E_p = \frac{1}{2} CV^2$, so $V = \sqrt{\frac{2 E_p}{C}}$

$$V = \sqrt{\frac{2 (10^8 \text{ J})}{400 \times 10^{-6} \text{ F}}}$$

$$V = 2236 \text{ V}$$

4. $E_p = \frac{1}{2} CV^2$, so $V = \sqrt{\frac{2E_p}{C}}$

$$V = \sqrt{\frac{2 (72 \text{ J})}{0.25 \times 10^{-6} \text{ F}}}$$

$$V = 2.4 \times 10^4 \text{ V}$$

5. $V = \sqrt{\frac{2 E_p}{C}}$, $C = Q/V$, so $Q = CV$

$$V = \sqrt{\frac{2 (200 \text{ J})}{60 \times 10^{-6} \text{ F}}} = 2.58 \times 10^3 \text{ V}$$

$Q = (2.58 \times 10^3 \text{ V})(60 \times 10^{-6} \text{ F}) = 0.155$ C on one plate and (-) 0.155 C on other plate

7E3, ENERGY STORED IN AN INDUCTOR

2. (a) $L = \mu_0 N^2 \frac{A}{\ell}$, $A = \pi r^2$

$$L = (4\pi \times 10^{-7} \tfrac{\text{H}}{\text{m}})(3500)^2 \left[\frac{\pi(0.05 \text{ m})^2}{0.07 \text{ m}}\right]$$

$$L = 1.73 \text{ H}$$

(b) $B = \mu_0 \frac{NI}{\ell}$

$$= \frac{(4\pi \times 10^{-7} \frac{\text{H}}{\text{m}})(3500)(0.5 \text{ A})}{0.07 \text{ m}}$$

$$B = 3.14 \times 10^{-2} \text{ T}$$

(c) $E = \frac{1}{2} LI^2$

$$= \tfrac{1}{2} (1.73\text{H})(0.5 \text{ A})^2$$

$$E = 0.216 \text{ J}$$

7E4, SERIES AND PARALLEL CAPACITORS

1. $C_p = C_1 + C_2 + C_3 + \ldots$; $\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$

(a) $\frac{1}{C_s} = \frac{1}{36 \times 10^{-6}\ f} + \frac{1}{18 \times 10^{-6}\ f} + \frac{1}{12 \times 10^{-6}\ f} = 1.67 \times 10^5/f$

$C_s = 6 \times 10^{-6}\ f$

(b) $C_p = 1 \times 10^{-6}\ f + 2 \times 10^{-6}\ f + 3 \times 10^{-6}\ f = 6 \times 10^{-6}\ f$

(c) $\frac{1}{C_s} = \frac{1}{12 \times 10^{-6}\ f} + \frac{1}{(2 \times 10^{-6}\ f)(4 \times 10^{-6}\ f)} = 2.5 \times 10^5/f$

$C_s = 4 \times 10^{-6}\ f$

2. $E_T = \frac{1}{2} C_T V^2$; $Q_T = C_T V$

(a) $E_T = \frac{1}{2} (6 \times 10^{-6}\ f)(108\ V)^2 = 3.5 \times 10^{-2}\ J$

$Q_T = (6 \times 10^{-6}\ f)(108\ V) = 6.48 \times 10^{-4}\ C$

(b) $E_T = \frac{1}{2} (6 \times 10^{-6}\ f)(18\ V)^2 = 9.72 \times 10^{-4}\ J$

$Q_T = (6 \times 10^{-6}\ f)(18\ V) = 1.1 \times 10^{-4}\ C$

(c) $E_T = \frac{1}{2} (4 \times 10^{-6}\ f)(20\ V)^2 = 8 \times 10^{-4}\ J$

$Q_T = (4 \times 10^{-6}\ f)(20\ V) = 8 \times 10^{-5}\ C$

3. $V = \frac{Q}{C}$; $Q_T = Q_1 = Q_2 = Q_3 = 6.48 \times 10^{-4}\ C$

(a) $V_1 = \frac{6.48 \times 10^{-4}\ C}{36 \times 10^{-6}\ f} = 18\ V$

(b) $V_2 = \frac{6.48 \times 10^{-4}\ C}{18 \times 10^{-6}\ f} = 36\ V$

(c) $V_3 = \frac{6.48 \times 10^{-4}\ C}{12 \times 10^{-6}\ f} = 54\ V$

4. $V_T = V_1 = V_2 = V_3 = 18\ V$; $Q = CV$

$Q_1 = (1 \times 10^{-6}\ f)(18\ V) = 1.8 \times 10^{-5}\ C$

$Q_2 = (2 \times 10^{-6}\ f)(18\ V) = 3.6 \times 10^{-5}\ C$

$Q_3 = (3 \times 10^{-6}\ f)(18\ V) = 5.4 \times 10^{-5}\ C$

7T1, HEAT STORAGE SYSTEMS

2. ΔH = specific heat x weight x ΔT

$= (1 \frac{Btu}{lb \cdot F^\circ})(10{,}000\ lb)(80\ F^\circ)$

$\Delta H = 800{,}000\ Btu$

3. ΔH = specific heat x weight x ΔT ; so weight = $\frac{\Delta H}{\text{specific heat x } \Delta T}$

$\Delta H_{water} = (1 \frac{Btu}{lb \cdot F^\circ})(10\ lb)(10\ F^\circ) = 100\ Btu$

$\Delta W_{glass\ wool} = \frac{100\ Btu}{(0.157 \frac{Btu}{lb \cdot F^\circ})(10\ F^\circ)} = 63.7\ lb$

7T2, ELECTRICAL EQUIVALENT OF HEAT

1. $E_e = QV$

$= (16\ C)(22.5\ V)$

$E_e = 360\ J$

2. $E_e = VIt$

$= (115\ V)(0.45\ A)(60\ s)$

$E_e = 3105\ J$

3. $E_h = mc\ (T_2 - T_1)$; so $T_2 = \frac{E_h + mcT_1}{mc}$

$T_2 = \frac{(3105\ J)(\frac{1\ cal}{4.184\ J}) + (1000\ g)(1\ cal/g \cdot C^\circ)(2^\circ C)}{(1000\ g)(1\ cal/g \cdot C^\circ)}$

$T_2 = 2.74^\circ C$

5. $P = \frac{E}{t}$; $E = mc\Delta T$; so $t = \frac{E}{P} = \frac{mc\Delta T}{P}$; $1\ watt = \frac{1\ J}{s}$

$t = \frac{(250\ g)(1\ cal/g \cdot C^\circ)(25\ C^\circ)}{(250\ J/s)(\frac{1\ cal}{4.184\ J})}$

$t = 104.6\ s$

3. $E_p = mgh$; $H = mc\,(T_2 - T_1)$, so $(T_2 - T_1) = \frac{H}{mc}$

(a) $E_p = (10\text{ kg})(9.8\text{ m/s}^2)(40\text{ m}) = 3920\text{ J}$

$$(T_2 - T_1) = \Delta T = \frac{(3920\text{ J})(\frac{1\text{ cal}}{4.184\text{ J}})}{(10{,}000\text{ g})(0.031\text{ cal/g}\cdot\text{C}^\circ)} = 3\text{ C}^\circ$$

(b) $E_p = (500\text{ kg})(9.8\text{ m/s}^2)(40\text{ m}) = 196{,}000\text{ J}$

$$(T_2 - T_1) = \Delta T = \frac{(196{,}000\text{ J})(\frac{1\text{ cal}}{4.184\text{ J}})}{(500{,}000\text{ g})(0.031\text{ cal/g}\cdot\text{C}^\circ)} = 3\text{ C}^\circ$$

4. $E_p = mgh$; $\Delta T = \frac{H}{mc}$; $H = mgh\,(\frac{1\text{ cal}}{4.184\text{ J}})$, so $\Delta T = \frac{mgh\,(\frac{1\text{ cal}}{4.184\text{ J}})}{m\,(\frac{10^3\text{ g}}{\text{kg}})\,c}$

$$\Delta T = \frac{(9.8\text{ m/s}^2)(6\text{ m})(\frac{1\text{ cal}}{4.184\text{ J}})}{(10^3\text{ g/kg})(0.093\text{ cal/g}\cdot\text{C}^\circ)}$$

$\Delta T = 0.15\text{ C}^\circ$

5. (a) $E_K = \frac{1}{2}mv^2$

$E_K = (\frac{1}{2})(0.03\text{ kg})(300\text{ m/s})^2 = 1350\text{ J}$

(b) $1\text{ cal} = 4.184\text{ J}$

$H = (0.90)(1350\text{ J})(\frac{1\text{ cal}}{4.184\text{ J}}) = 290.4\text{ cal}$

(c) $H = mc\Delta T$ until a temperature of 330°C is reached, then $H = mL$ until all of the bullet is melted, so $H_{TOT} = mc\,(330^\circ\text{C} - T_1) + m'L$, where m' is the mass of lead that melts and L is the heat necessary to melt one gram of lead.

$H = mc\,(330^\circ\text{C} - T_1) + m'L$

$290.4\text{ cal} = (30\text{ g})(0.031\text{ cal/g}\cdot\text{C}^\circ)(330^\circ\text{C} - 30^\circ\text{C}) + m'\,(5.9\text{ cal/g})$

$m' = 1.93\text{ g}$

The final temperature of the bullet is 330°C; 1.93 g of the bullet's mass is melted.

6. (a) $W = Fd$

$W = (50\text{ lb})(10\text{ ft}) = 500\text{ ft}\cdot\text{lb}$

(b) $E_p = (\text{weight})(\text{height})$

$E_p = (375\text{ lb})(15\text{ in})(\frac{1\text{ ft}}{12\text{ in}}) = 468.75\text{ ft}\cdot\text{lb}$

$W = E_p = (500\text{ ft}\cdot\text{lb}) - (468.75\text{ ft}\cdot\text{lb}) = 31.25\text{ ft}\cdot\text{lb}$

The energy probably was converted to heat by friction in the pulley system.

(c) $n = \frac{W_{out}}{W_{in}} (100)$

$n = \frac{468.75 \text{ ft·lb}}{500 \text{ ft·lb}} (100) = 93.75\%$

7T4, THERMAL DRYING

Calculations require data from laboratory.

7T5, MIXING LIQUIDS AT DIFFERENT TEMPERATURES

3. $m_1c_1(T_1 - T_f) + m_2c_2(T_2 - T_f) = 0$, so $c_2 = \frac{-m_1c_1(T_1 - T_f)}{m_2(T_2 - T_f)}$

$c_2 = \frac{-(100 \text{ g})(0.8 \text{ cal/g·C°})(20°C - 37°C)}{(200 \text{ g})(70°C - 37°C)}$

$c_2 = 0.206 \text{ cal/g·C°}$

4. $m_1c_1(T_1 - T_f) + m_2c_2(T_2 - T_f) = 0$, so $T_f = \frac{m_1c_1T_1 + m_2c_2T_2}{m_1c_1 + m_2c_2}$

$T_f = \frac{(95 \text{ g})(1.0 \text{ cal/g·C°})(25°C) + (210 \text{ g})(0.8 \text{ cal/g·C°})(75°C)}{(95 \text{ g})(1.0 \text{ cal/g·C°}) + (210 \text{ g})(0.8 \text{ cal/g·C°})}$

$T_f = 56.94°C$

3. $F_2x_2 = F_1x_1$; $F_2 = \frac{F_1x_1}{x_2}$

$F_2 = \frac{(300\ lb)(1.5\ ft)}{4\ ft}$

$F_2 = 112.5\ lb$

4. T = Component of weight parallel to cable

$T = (3000\ lb)(\sin 25°)$

$T = 1268\ lb$

5. $M_i = \frac{x_2}{x_1}$; $M_a = \frac{F_1}{F_2}$; $\eta = \frac{M_a}{M_i}(100)$

$M_i = \frac{\frac{1}{2}(60\ in)}{\frac{1}{2}(5\ in)} = 12$

$M_a = \frac{2400\ lb}{250\ lb} = 9.6$

$\eta = (\frac{9.6}{12})(100) = 80\%$

6. (a) $M_i = \frac{2\pi r^2}{x_1}$, in ideal case $M_i = M_a = \frac{F_1}{F_2}$, so $F_2 = \frac{F_1}{M_i} = \frac{F_1x_1}{2\pi r^2}$

$F_2 = \frac{(4000\ lb)(0.25\ in)}{2\pi\ (20\ in)} = 7.96\ lb$

(b) $\eta = \frac{F_2\ (ideal)}{F_2\ (actual)}(100)$, so $F_2\ (actual) = \frac{F_2\ (ideal)(100)}{\eta}$

$F_2\ (actual) = \frac{(7.96\ lb)(100)}{20} = 39.8\ lb$

7. (a) $M_i = \frac{A_1}{A_2} = \frac{F_1}{F_2}$, so $F_2 = F_1(\frac{A_2}{A_1})$; $A = \pi r^2$

$F_2 = (50\ tons)\left[\frac{\pi(\frac{4\ in}{2})^2}{\pi(\frac{64\ in}{2})^2}\right] = 0.195\ tons\ (\frac{2000\ lb}{ton}) = 390.6\ lb$

(b) $\frac{x_2}{x_1} = \frac{A_1}{A_2}$, so $x_2 = x_1(\frac{A_1}{A_2})$

$x_2 = 1\ in\left[\frac{\pi(32\ in)^2}{\pi(2\ in)^2}\right] = 256\ in = 21.3\ ft$

8. $V_1 = (\frac{N_1}{N_2})V_2$

$= (\frac{48\ turns}{720\ turns})(120\ V)$

$V_1 = 8\ V$

8M1, LEVERS

1. $\frac{F_1}{F_2} = \frac{\ell_1}{\ell_2}$; $\ell_2 = \ell_1 \frac{F_1}{F_2}$

$\ell_2 = 6 \text{ ft } (\frac{95 \text{ lb}}{85 \text{ lb}})$

$\ell_2 = 6.7 \text{ ft}$

3. $\frac{F_2}{F_1} = \frac{\ell_1}{\ell_2}$; $F_1 = F_2 \frac{\ell_2}{\ell_1}$

$F_1 = 32 \text{ lb } (\frac{6.5 \text{ in}}{1.25 \text{ in}})$

$F_1 = 166.4 \text{ lb}$

4. $\frac{F_2}{F_1} = \frac{\ell_1}{\ell_2}$; $F_1 = F_2 \frac{\ell_2}{\ell_1}$

$F_1 = 210 \text{ lb } (\frac{4 \text{ in}}{24 \text{ in}})$

$F_1 = 35 \text{ lb}$

5. $M_i = \frac{\ell_2}{\ell_1} = \frac{19 \text{ in}}{1.5 \text{ in}} = 12.7$

$M_a = \frac{F_1}{F_2} = \frac{600 \text{ lb}}{50 \text{ lb}} = 12$

$\eta = \frac{M_a}{M_i} (100) = \frac{12}{12.7} (100) = 94.5\%$

8M2, WEDGES AND INCLINED PLANES

1. $2 F_x = \frac{F_o}{\tan \theta}$

$= \frac{90 \text{ N}}{\tan (6°)}$

$2 F_x = 856.3 \text{ N}$

2. $2 F_x = \frac{F_o}{\tan \theta}$

(a) $2 F_x = \frac{(0.5 \text{ kg})(9.8 \text{ m/s}^2)}{\tan (4°)} = 70.1 \text{ N}$

(b) $2 F_x = \frac{(500 \text{ g})(980 \text{ cm/s}^2)}{\tan (4°)} = 7.01 \times 10^6 \text{ dynes}$

3. theoretical MA $= \frac{1}{\tan \theta}$

(a) theoretical MA $= \frac{1}{\tan (6°)} = 9.5$

(b) theoretical MA $= \frac{1}{\tan (4°)} = 14.3$

4. MA (actual) $= \frac{2 F_x}{F_o}$; MA (theoretical) $= \frac{1}{\tan \theta}$; Eff $= \frac{\text{MA (actual)}}{\text{MA (theoretical)}} (100)$

Eff $= \frac{(280 \text{ lb})(45 \text{ lb})}{1/\tan (7.5°)} (100)$

Eff = 81.9%

5. Eff $= \frac{2 F_x/F_o}{1/\tan \theta} (100)$; so $2 F_x = \frac{\text{Eff } (F_o)}{\tan \theta (100)}$

$2 F_x = \frac{(90)(45 \text{ lb})}{\tan (7.5°)(100)}$

$2 F_x = 307.6$ lb

8M3, DRIVE SYSTEMS

1. $M = \frac{n_2}{n_1}$

$= \frac{56 \text{ teeth}}{18 \text{ teeth}}$

M = 3.1

2. $M = \frac{r_2}{r_1}$

$= \frac{(14 \text{ in})(\frac{1}{2})}{(2.5 \text{ in})(\frac{1}{2})}$

M = 5.6

3. System $M_{(r_1 \text{ to } r_3)} = M_{(r_1 \text{ to } r_2)} \times M_{(r_2 \text{ to } r_3)} = (\frac{r_2}{r_1})(\frac{r_3}{r_2}) = \frac{r_3}{r_1}$

$= \frac{5.75 \text{ in}}{0.1065 \text{ in}}$

System $M_{(r_1 \text{ to } r_3)} = 54$

4. $M = \frac{\omega_1}{\omega_3}$, so $\omega_1 = M\omega_3$; $M = \frac{\tau_3}{\tau_1}$, so $\tau_3 = M\tau_1$

(a) $\tau_3 = (54)(0.42 \text{ oz-in}) = 22.68$ oz·in

(b) $\omega_1 = (54)(33\ 1/3 \text{ rev/min}) = 1800$ rev/min

8M4, GEAR TRAINS

3. $M = (\frac{N_2}{N_1})(\frac{N_3}{N_3})$

$= (\frac{26}{19})(\frac{27}{18})$

$M = 2.1$

8M5, BLOCK AND TACKLE

1. $n = \frac{F_L}{F_A}(\frac{1}{N})(100)$

$= (\frac{95\ lb}{40\ lb})(\frac{1}{6})(100)$

$n = 39.6\%$

2. $n = \frac{F_L}{F_A}(\frac{1}{N})(100)$; so $F_L = n(F_A)(N)(\frac{1}{100})$

$F_L = (80)(240\ lb)(3)(0.01)$

$F_L = 576\ lb$

3. $n = \frac{F_L}{F_A}(\frac{1}{N})(100)$; so $N = (\frac{F_L}{F_A})(100)(\frac{1}{n})$

$N = (\frac{790\ lb}{100\ lb})(100)(\frac{1}{79})$

$N = 10$ pulleys

8M6, DIFFERENTIAL HOIST

2. $F_A = \frac{F_L}{n}(\frac{D - d}{2\ D})$

$= (\frac{790\ lb}{0.35})(\frac{12\ in - 10\ in}{2\ (12\ in)})$

$F_A = 188.1\ lb$

3. $F_A = \frac{F_L}{\eta}\left(\frac{D - d}{2D}\right)$; so $F_L = \frac{F_A\,(\eta)(2D)}{D - d}$

$$F_L = \frac{(175\ \text{lb})(0.33)[2\ (12\ \text{in})]}{12\ \text{in} - 10\ \text{in}}$$

$$F_L = 693\ \text{lb}$$

4. (a) $M_a = \frac{S_A}{S_L} = \frac{2D}{D - d}$; so $S_A = \left(\frac{2D}{D - d}\right) S_L$

$$S_A = \left(\frac{2\ (25\ \text{cm})}{25\ \text{cm} - 20\ \text{cm}}\right)\ (2\ \text{m}) = 20\ \text{m}$$

(b) $F_A = \frac{F_L}{\eta}\left(\frac{D - d}{2D}\right)$; $W = mg$

$$F_A = \left(\frac{(100\ \text{kg})(9.8\ \text{m/s}^2)}{0.75}\right)\left(\frac{50\ \text{m}}{50\ \text{cm}}\right) = 130.7\ \text{N}$$

8F1, HYDRAULIC PRESS

3. $F_2 = \left(\frac{A_2}{A_1}\right) F_1$; $F_2 s_2 = F_1 s_1$; so $s_2 = \frac{F_1 s_1}{F_2}$

$$F_2 = \frac{\frac{\pi}{4}(12\ \text{in})^2}{\frac{\pi}{4}(1\ \text{in})^2}\ (1000\ \text{lb}) = 144{,}000\ \text{lb}$$

$$s_2 = \frac{(1000\ \text{lb})(21\ \text{in})}{144{,}000\ \text{lb}} = 0.146\ \text{in}$$

8E1, ELECTRICAL TRANSFORMERS

1. $\frac{V_s}{V_p} = \frac{N_s}{N_p}$; so $V_s = \left(\frac{N_s}{N_p}\right) V_p$; $\frac{I_s}{I_p} = \frac{N_p}{N_s}$, so $I_s = \left(\frac{N_p}{N_s}\right) I_p$

$$V_s = \left(\frac{900\ \text{turns}}{400\ \text{turns}}\right)\ (8\ \text{V}) = 18\ \text{V}$$

$$I_s = \left(\frac{400\ \text{turns}}{900\ \text{turns}}\right)\ (0.4\ \text{A}) = 0.178\ \text{A}$$

2. $V_s = \left(\frac{N_s}{N_p}\right) V_p$; $I_s = \left(\frac{N_p}{N_s}\right) I_p$

$$V_s = \left(\frac{200\ \text{turns}}{1000\ \text{turns}}\right)\ (10\ \text{V}) = 2\ \text{V}$$

$$I_s = \left(\frac{1000\ \text{turns}}{200\ \text{turns}}\right)\ (0.8\ \text{A}) = 4\ \text{A}$$

3. $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

$\frac{N_s}{N_p} = \frac{3\ V}{12\ V} = \frac{1}{4}$ or $\frac{N_p}{N_s} = \frac{12\ V}{3\ V} = 4$

4. $\frac{I_s}{I_p} = \frac{N_p}{N_s}$

$\frac{N_p}{N_s} = \frac{0.1\ A}{2\ A} = 0.05$ or $\frac{N_s}{N_p} = \frac{2\ A}{0.1\ A} = 20$

6. $\frac{R_p}{R_s} = \left(\frac{N_p}{N_s}\right)^2$, so $R_p = \left(\frac{N_p}{N_s}\right)^2 R_s$

$R_p = \left(\frac{3600\ turns}{600\ turns}\right)^2 50\ \Omega$

$R_p = 1800\ \Omega$

7. $\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$; $V = IR$, so $I = \frac{V}{R}$

$\frac{2000\ turns}{4000\ turns} = \frac{V_s}{100\ V}$; $V_s = 50\ V$

$I_s = \frac{50\ V}{50\ \Omega} = 1\ A$

$I_p = I_s\left(\frac{N_s}{N_p}\right) = 1A\left(\frac{2000\ turns}{4000\ turns}\right) = 0.5\ A$

9-0, ENERGY CONVERTERS

3. $\eta = \frac{E_{out}}{E_{in}}(100) = \frac{P_{out}}{P_{in}}(100)$, so $P_{in} = \frac{P_{out}}{\eta}(100)$

$$P_{in} = \frac{(10\ hp)(\frac{746\ W}{hp})(\frac{1\ kW}{1000\ W})}{82}(100)$$

$$P_{in} = 9.1\ kW$$

4. $\eta = \frac{P_{out}}{P_{in}}(100)$; so $P_{out} = \frac{\eta\ (P_{in})}{100}$; $P = \frac{E}{t}$

$$P_{out} = \frac{(8.7)(\frac{750\ J}{3\ s})}{100}$$

$$P_{out} = 21.75\ W$$

5. $E = mgh$; $\eta_T = \eta_1\eta_2\eta_3\eta_4\eta_5\eta_6$; $\eta_T = \frac{E_{out}}{E_{in}}(100)$

$\eta_T = (0.75)(0.82)(0.62)(0.79)(0.93)(0.96) = 0.27$ or 27%

$E_{out} = (1000\ kg)(9.8\ m/s^2)(2\ m) = 19,600\ J$

$$E_{in} = \frac{E_{out}}{\eta_T}(100) = \frac{19,600\ J}{27}(100) = 72,593\ J$$

$$m = \frac{72,593\ J\ (\frac{1\ Btu}{1054\ J})}{13,500\ Btu/lb} = 5.1 \times 10^{-3}\ lb \approx 2.3 \times 10^{-3}\ kg$$

9F1, TURBINES

5. $P_{in} = p\frac{V}{t}$; $\eta = \frac{P_{out}}{P_{in}}(100)$; $P_{out} = \frac{P_{in}\ (\eta)}{100}$

$$P_{in} = (100\ \frac{lb}{in^2})(\frac{144\ in^2}{1\ ft^2})(\frac{400\ ft^3}{60\ s}) = 96,000\ lb\cdot ft/s$$

$$P_{in} = 96,000\ \frac{lb\cdot ft}{s}\left(\frac{1\ hp}{550\ \frac{lb\cdot ft}{s}}\right) = 174.5\ hp$$

$$P_{out} = \frac{(174.5\ hp)(75)}{100} = 130.9\ hp$$

$$P_{in} = 174.5\ hp\left(\frac{550\ \frac{lb\cdot ft}{s}}{1\ hp}\right)(\frac{4.45\ N}{lb})(\frac{1\ m}{3.28\ ft})(\frac{1\ kW}{1000\ W}) = 130\ kW$$

$$P_{out} = 130.9\ hp = (130.9\ hp)(0.746\ \frac{kW}{hp}) = 97.7\ kW$$

9F2, FLUID PUMPS

No calculations required.

9F3, WIND POWER

1. $P = (1.37 \times 10^{-5})\,Av^3$, $A = \pi r^2$; $P_{max} = (8.12 \times 10^{-6})\,Av^3$

(a) $A = \pi(4\text{ m})^2 = 50.3\text{ m}^2$

$P = (1.37 \times 10^{-5})(50.3)(32)^3$

$P = 22.6\text{ kW}$

(b) $P_{max} = 8.12 \times 10^{-6}\,(50.3)(32)^3$

$P_{max} = 13.4\text{ kW}$

2. $\Delta p = \dfrac{P_{actual}}{P_{wind}}$

$= \dfrac{11\text{ kW}}{22.6\text{ kW}}$

$\Delta p = 0.487$

3. $\Delta p = \dfrac{P_{actual}}{1.37 \times 10^{-5}\,(Av^3)}$; $P_{actual} = 1.37 \times 10^{-5}\,(Av^3)\,\Delta p$

$P_{actual} = 1.37 \times 10^{-5}\,(25)(25)^3(0.35)$

$P_{actual} = 1.87\text{ kW}$

9F4, FANS AND BLOWERS

4. $\eta_s = \dfrac{Ahp_s}{P_{in}}$, $\eta_t = \dfrac{Ahp_s}{P_{in}}$

$\eta_s = \dfrac{Q_v \Delta p_s}{6356} \Big/ P_{in} = \dfrac{(3600\text{ cfm})(2.5\text{ in})}{(6356)(2\text{ hp})}\,(100\%) = 70.8\%$

$\eta_t = \dfrac{Q_v \Delta p_t}{6356\,(P_{in})} = \dfrac{(3600\text{ cfm})(2.5\text{ in} + 0.5\text{ in})}{(6356)(2\text{ hp})}\,(100\%) = 85.\%$

5. $\eta_s = \frac{Q_V \Delta p_s}{6356\ P_{in}}(100\%)$; $\eta_t = \frac{Q_V \Delta p_t}{6356\ P_{in}}(100\%)$; $\eta_t = \eta_s + 10\%$

$\eta_s = \frac{(2000\ \text{cfm})(2.6\ \text{in})}{6356\ (1\ \text{hp})}(100\%) = 81.8\%$

$\eta_t = \eta_s + 10\% = 91.8\% = \frac{(2000\ \text{cfm})(2.6\ \text{in} + \Delta p_v)}{6356\ (1\ \text{hp})}\ (100\%)$

$\Delta p_v = 0.32$ in

9F5, VACUUM PUMPS

2. $t = \frac{2.3\ V}{s}\ \log_{10}\frac{p_1}{p_2}$

$t = \frac{2.3\ (100\ \ell)}{100\ \ell/s}\ \log_{10}\frac{1\ \text{torr}}{10^{-3}\ \text{torr}}$

$t = 11.5$ s

3. $Z = \frac{1}{C} = \frac{p_1 - p_2}{p_1 V_1}$; $V = LA$

If p_1 is 1 torr, as in the previous problem, then

$Z = \frac{1\ \text{torr} - 1 \times 10^{-3}\ \text{torr}}{(1\ \text{torr})(0.5\ \text{m})(\pi)(0.025\ \text{m})^2} = 1.02 \times 10^3/\text{m}^3$

9E1, ELECTRIC GENERATORS

No calculations required.

9E2, ALTERNATORS

3. $f = N\omega$, $N = \frac{f}{\omega}$

$N = \frac{60\ \text{Hz}}{360\ \text{rev}/60\ \text{s}} = 10$ pole pairs

Each pair of poles must have a coil in the stator to operate efficiently, so there must be 10 coils in the stator.

5. $f = N\omega$, Number of coils = Number of pole pairs

$f = 27\ (420\ \text{rev}/60\ \text{s})$

$f = 189$ Hz

9E3, ELECTRIC MOTORS

1. (a) Out of the page.

   (b) Downward.

2. (a) Counterclockwise (If this is the initial position the loop does not rotate at all since no torque is produced.)

   (b) Counterclockwise.

   (c) Clockwise.

9E4, SOLENOIDS AND RELAYS

No calculations required.

9E5, PHOTOVOLTAIC MATERIALS

3. $I = RP$

$$I = \left(\frac{0.5 \times 10^{-6}\ A}{1 \times 10^{-6}\ W}\right)(10 \times 10^{-3}\ W) = 5 \times 10^{-3}\ A$$

4. $Eff = (R^2PR_L)(100\%)$

$$= \left(\frac{0.5 \times 10^{-6}\ A}{1 \times 10^{-6}\ W}\right)^2 (10 \times 10^{-3}\ W)(120\ \Omega)(100\%)$$

$Eff = 30\%$

9T1, BOILERS

No calculations required.

9T2, THERMOELECTRIC GENERATORS

4. $V_s = (S_1 - S_2)(T_1 - T_2)$

$= (0.35\ mV/K - (-0.30\ mV/K)(600\ K - 350\ K)$

$V_s = 162.5\ mV$

5. $\eta_{max} = \left(\frac{T_1 - T_2}{T_1}\right)\left(\frac{M - 1}{M + T_2/T_1}\right)$

$M = [1 + Z\,(T_1 + T_2)/2]^{\frac{1}{2}} = [1 + (0.0032/K)(950\ K + 273\ K)/2]^{\frac{1}{2}}$

$M = 1.72$

$\eta_{max} = \left(\frac{950\ K - 273\ K}{950\ K}\right)\left(\frac{1.72 - 1}{1.72 + \frac{273\ K}{950\ K}}\right) = 0.256$ or 25.6%

9T3, SOLAR COLLECTORS

4. $\eta = \frac{P_{out}}{P_{in}}(100)$; $\quad 90\ \frac{mW}{cm^2} = 0.90\ \frac{kW}{cm^2}$ (See Figure 2)

$= \frac{5\ kW}{(0.90\ \frac{kW}{m^2})(10\ m^2)}(100)$

$\eta = 55.6\%$

5. $\eta = \frac{P_{out}}{P_{in}}(100)$; $\quad P_{out} = IV$

$= \frac{(0.7\ A)(2\ V)}{(100 \times 10^{-3}\ \frac{W}{cm^2})(120\ cm^2)}(100)$

$\eta = 11.7\%$

10-0, TRANSDUCERS

No calculations required.

10M1, STRAIN GAGES

4. $GS = \frac{\Delta R}{R}$, so $G = \frac{\Delta R}{RS}$

$$G = \frac{(401\ \Omega - 400\ \Omega)}{(400\ \Omega)(10^{-3})}$$

$G = 2.5$

10M2, ACCELEROMETERS

5. $a = \frac{V}{s}$

$$= \frac{(0.55 \times 10^{3})\ mV}{15\ mV/g}$$

$a = 36.7\ g = (3.67)(32.2\ ft/s^2) = 1182\ ft/s^2$

6. $a = \frac{V}{s}$, so $V = as$

$V = (2.6\ g)(12\ mV/g)$

$V = 31.2\ mV$

10F1, BOURDON TUBES

3. Beryllium-Copper and Ni-Span C Alloy.

10F2, ANEROID BAROMETERS

4.

DATA TABLE 2				
lb/in²	in Hg	mm Hg	torr	mb
15.2	30.9	785.9	785.9	1047.5
13.7	27.8	706.1	706.1	941.2
10.6	21.7	550	550	733.1
13.2	26.8	680	680	906.4
13.1	26.6	675.2	675.2	900

10F3, DIFFERENTIAL PRESSURE TRANSDUCERS

1. psia = psig + 14.7

   (a) psia = 3.0 psig + 14.7 = 17.7 psia

   (b) psia = 16.0 psig + 14.7 = 30.7 psia

   (c) psia = 152.0 psig + 14.7 = 166.7 psia

   (d) psia = 256.0 psig + 14.7 = 270.7 psia

10F4, FLUID FLOW MEASURING DEVICES

No calculations required.

10F5, VACUUM GAGES

2. $\lambda = \frac{Cg}{n}$; $p = nkT$, so $\lambda = \frac{Cg}{p/kT} = \frac{CgkT}{p}$ assume T = 25°C

$$\lambda_1 = \frac{(1.66 \times 10^{14}\ /cm^2)(1.38 \times 10^{-16}\ erg/K)[(273 + 25)\ K]}{10\ torr\ (\frac{1333\ dynes/cm^2}{1\ torr})} = 5.12 \times 10^{-4}\ cm$$

$$\lambda_2 = \frac{(1.66 \times 10^{14}\ /cm^2)(1.38 \times 10^{-16}\ erg/K)(298\ K)}{(1 \times 10^{-11}\ torr)(\frac{1333\ dynes/cm^2}{1\ torr})} = 5.12 \times 10^{6}\ cm$$

10E1, METER MOVEMENTS

No calculations required.

10T1, AUTOMOBILE THERMOSTATS

No calculations required.

10T2, BIMETALLIC STRIPS

4. $x = 3\,(\alpha_A - \alpha_B)(T_2 - T_1)\,\ell^2/4d$, so $(\alpha_A - \alpha_B) = \dfrac{x\,(4\,d)}{3\,(T_2 - T_1)\,\ell^2}$

$$(\alpha_A - \alpha_B) = \frac{(0.23\text{ cm})(4)(0.1\text{ cm})}{3\,(15\text{ C}^\circ)(18\text{ cm})^2}$$

$$(\alpha_A - \alpha_B) = 6.31 \times 10^{-6}/\text{C}^\circ$$

5. $x = 9\,(\alpha_A - \alpha_B)(T_2 - T_1)\,r\,\ell/4d$, so $T_2 - T_1 = \dfrac{x\,(4\,d)}{9(\alpha_A - \alpha_B)(r\,\ell)}$

$$(T_2 - T_1) = \frac{(0.675\text{ cm})(4)(0.05\text{ cm})}{9(17 \times 10^{-6}\text{ C}^{\circ -1} - 5 \times 10^{-6}\text{ C}^{\circ -1})(5\text{ cm})(25\text{ cm})}$$

$$(T_2 - T_1) = 10\text{ C}^\circ$$

10T3, TEMPERATURE MEASURING DEVICES

No calculations required.

10T4, THERMOCOUPLES

2. (a) $T = 310°F$

(b) $V = V_1 + V_2$

$V = 0.83\ mV + 6.92\ mV = 7.75\ mV$

$T = 339°F$

3. $°F = \frac{9}{5} C + 32 = \frac{9}{5} (1500°C) + 32 = 2732°F$

$V = 15.53\ mV$

4. (a) $V_{AB} = V_{AC} - V_{BC}$; $V_{Fe-Cu} = V_{Fe-C} - V_{Cu-C}$

$V_{Fe-Cu} = 16.33\ mV - 14.86\ mV$

$V_{Fe-Cu} = 1.47\ mV$

(b) $V_{Fe-Cu} = V_{Fe-Pb} - V_{Au-Pb}$

$V_{M-Pb} = aT + \frac{1}{2} bT^2$

$V_{Fe-Pb} = (16.6\ \mu V/C°)\ 300°C + \frac{1}{2} (-0.030\ \mu V/(C°)^2)(300°C)^2 = 3630\ \mu V$

$V_{Cu-Pb} = (2.76\ \mu V/C°)\ 300°C + \frac{1}{2} (0.012\ \mu V/(C°)^2)(300°C)^2 = 1368\ \mu V$

$V_{Fe-Cu} = 3.63\ mV - 1.37\ mV = 2.26\ mV$

5. $V = 0.1\ V/5 = 20\ mV$

$T = 366°C$

6. $S = \Delta V/\Delta T$

$S = \frac{14.39\ mV - 14.34\ mV}{265°C - 264°C} = 0.05\ mV/°C$

10T5, THERMISTORS

4. If the temperature decreases, the resistance in the thermistor will increase, and reduced current will flow in the circuit. This decrease in current <u>decreases</u> the voltage drop across R_2. ($V = IR$)

5. If the temperature increases R_2 will increase. The current stays the same since R_1 and R_2 are identical except for the fact that R_1 has an NTC and R_2 has a PTC. Since $E_{out} = IR_2$, E_{out} will increase.

10T6, PYROMETERS

4. From Figure 4, the true temperature is approximately 2050°C.

5. $P = \sigma A \varepsilon T^4$, so $\varepsilon = \frac{P}{\sigma A T^4}$

$$\varepsilon = \frac{212.2\ W}{(5.669 \times 10^{-12}\ W/cm^2 \cdot deg^4)(50\ cm^2)(1150°K)} = 0.428$$

$$P = (5.669 \times 10^{-12}\ W/cm^2 \cdot deg^4)(50\ cm^2)(0.428)(1300°K)^4 = 346.5\ W$$

6. $P = \sigma A \varepsilon T^4$, so $\varepsilon = \frac{P}{\sigma A T^4}$

$$\varepsilon = \frac{1\ W}{(5.669 \times 10^{-12}\ W/cm^2 \cdot deg^4)(1\ cm^2)[(327 + 273)°K]^4}$$

$\varepsilon = 1.36$, Since ε can never have a value greater than one, the original data must be incorrect.

11-0, VIBRATIONS AND WAVES

3. (a) $v = f\lambda$, so $f = \frac{v}{\lambda}$

$$f = \frac{3 \times 10^8 \text{ m/s}}{555 \times 10^{-9} \text{ m}} = 5.4 \times 10^{14} \text{ Hz}$$

(b) $v = f\lambda$, so $\lambda = \frac{v}{f}$

$$\lambda = \frac{1130 \text{ ft/s}}{980/\text{s}} = 1.15 \text{ ft}$$

11M1, SPEED OF SOUND IN MATERIALS

2. Velocity of sound increases with the square root of the absolute temperature.

v_{air} at 0°C = 331.7 m/s

$$v = (331.7 \text{ m/s})\left(\frac{273\text{K} + 57\text{K}}{273\text{K}}\right)^{\frac{1}{2}}$$

$v = 364.7$ m/s

3. $d = vt$ $\quad v_{ocean} = 1514$ m/s (Table 2), $t = \frac{d}{v}$

$d = (1514 \text{ m/s})(3 \text{ s}) = 4542$ m

$t_{air} = \frac{4542 \text{ m}}{331.7 \text{ m/s}} = 13.7$ s $\quad \therefore$ Sound arrives through the air 10.7 s later.

11M2, REFLECTION AND ABSORPTION OF SOUND ENERGY

3. $L = 10 \log_{10} I/I_o$

$(10^{-10} \text{ W/cm}^2) - (10^{-10} \text{ W/cm}^2)(0.30) =$ reflected sound energy

$7 \times 10^{-11} \text{ W/cm}^2 =$ reflected sound energy

$$L = 10 \log_{10} \left[\frac{(7 \times 10^{-11} \text{ W/cm}^2)\left(\frac{10^7 \text{ erg}}{1 \text{ J}}\right)}{10^{-2} \text{ erg/cm}^2 \cdot \text{s}} \right] = 58.5 \text{ dB}$$

4. $L = 10 \log_{10} I/I_o$

$$L_I = 10 \log_{10}\left(\frac{10^{-2} \text{ erg/cm}^2 \cdot \text{s}}{10^{-9} \text{ erg/cm}^2 \cdot \text{s}}\right) = 70 \text{ dB}$$

$$L_R = 10 \log_{10}\left(\frac{2.5 \times 10^{-3} \text{ erg/cm}^2 \cdot \text{s}}{10^{-9} \text{ erg/cm}^2 \cdot \text{s}}\right) = 63.98 \text{ dB}$$

$L_I - L_R =$ reduction in dB = 6.02 dB

11M3, VIBRATION ISOLATION

3. $T_I = \frac{a_s}{a_m}$

$= \frac{3 \text{ cm}}{5.5 \text{ cm}}$

$T_I = 0.545$

11M4, RESONANCE

5. $T = 2\pi \sqrt{\ell/g}$

(a) $T = 2\pi\sqrt{\frac{.25 \text{ cm}}{9.8 \text{ m/s}^2}}$

$T = 1 \text{ s}$

(b) $T = 2\pi \sqrt{\frac{5 \text{ m}}{9.8 \text{ m/s}^2}}$

$T = 4.5 \text{ s}$

6. $f_1 = \frac{1 (v)}{4\ell}$

(a) $f_1 = \frac{1 (346 \text{ m/s})}{4 (.5 \text{ m})}$

$f_1 = 173 \text{ Hz}$

(b) $f_1 = \frac{1 (346 \text{ m/s})}{4 (.375 \text{ m})}$

$f_1 = 231 \text{ Hz}$

11M5, SOUND SPEAKERS

No calculations required.

11F1, CAVITY VIBRATIONS AND STANDING WAVES

1. $f = \frac{v}{\lambda}$

$= \frac{3 \times 10^8 \text{ m/s}}{5 \times 10^{-7} \text{ m}}$

$f = 6 \times 10^{14} \text{ Hz}$

2. $f = \frac{v}{\lambda}$, so $\lambda = \frac{v}{f}$

$\lambda = \frac{335 \text{ m/s}}{800/\text{s}}$

$\lambda = 0.419 \text{ m}$

4. $\Delta f = \frac{v}{2\ell}$, $f_n = n\Delta f$

$\Delta f = \frac{335 \text{ m/s}}{2(3.2 \text{ m})} = 52.34 \text{ Hz}$

$f_1 = (1)(52.34 \text{ Hz}) = 52.34 \text{ Hz}$

$f_2 = (2)(52.34 \text{ Hz}) = 104.68 \text{ Hz}$

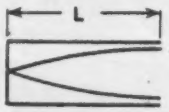
$f_3 = (3)(52.34 \text{ Hz}) = 157.02 \text{ Hz}$

5. $\Delta f = \frac{v}{2\ell}$

$= \frac{3 \times 10^8 \text{ m/s}}{2 (0.25 \text{ m})}$

$\Delta f = 6 \times 10^8 \text{ Hz}$

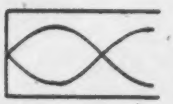
6. Mode 1 ;



$\lambda_1 = 4\ell$

$f_1 = \frac{v}{\lambda_1} = \frac{v}{4\ell}$

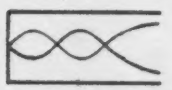
Mode 2;



$\lambda_2 = \frac{4}{3}\ell$

$f_2 = \frac{3v}{4\ell}$

Mode 3,



$\lambda_3 = \frac{4}{5}\ell$

$f_3 = \frac{5v}{4\ell}$

Mode 4; $\lambda_4 = \frac{4}{7}\ell$

$f_4 = \frac{7v}{4\ell}$

11F2, SPEAKER ENCLOSURES

No calculations required.

2. $d = v\,(t)$; depth of ocean $= \frac{d}{2}$

$d = (1450\ m/s)(4.6\ s) = 6670\ m$

depth $= \frac{d}{2} = 3335\ m$

3. $t = (0.05)(\frac{V}{a})$, $a = \beta_1 A_1 + \beta_2 A_2 + \ldots \beta_n A_n$

$a_1 = [(240)(0.025) + (200)(0.04) + (300)(0.06) + (1200)(0.04) + (38)(42)(0.04) +$
$(38)(42)(0.03) + (95)(0.3)]$ sabins

$a_1 = 220.22$ sabins (without students)

$a_2 = 220.22 + (50)(4.0) = 450.22$ sabins (with students)

$t_1 = (0.05)\frac{(38\ ft)(42\ ft)(10\ ft)}{220.22\ sabins} = 3.62\ s$

$t_2 = (0.05)\frac{(38\ ft)(42\ ft)(10\ ft)}{(420.22\ sabins)} = 1.90\ s$

4. $t = (0.05)(\frac{V}{a})$; $a = (0.05)\,(\frac{V}{t})$

$(420.22\ sabins) + (A)(0.82)\ sabins = (0.05)\frac{(38\ ft)(42\ ft)(10\ ft)}{0.8\ s}$

$(A)(0.82)\ sabins = 997.5\ sabins - 420.22\ sabins$

$A = 704\ ft^2$

11F4, DOPPLER EFFECT

1. (a) $f_o = f_s \left(1 + \frac{V_o}{v}\right)$

$= (1500 \times 10^3 \text{ Hz})\left(1 + \frac{30 \text{ m/s}}{330 \text{ m/s}}\right)$

$f_o = 1636 \times 10^3 \text{ Hz}$

(b) $f_o = \frac{f_s v}{v - v_s}$

$= \frac{(1500 \times 10^3 \text{ Hz})(330 \text{ m/s})}{330 \text{ m/s} - 30 \text{ m/s}}$

$f_o = 1650 \times 10^3 \text{ Hz}$

2. $f_o = \frac{f_s (v \pm v_o)}{(v \pm v_s)}$

$= \frac{(3000 \text{ Hz})(330 \text{ m/s} + 20 \text{ m/s})}{(330 \text{ m/s} - 75 \text{ m/s})}$

$f_o = 4117.6 \text{ Hz}$

4. $f_o = f_s \left(1 + \frac{u}{c}\right)$; $f_o - f_s = f_{beat} = f_s \left(\frac{u}{c}\right)$; so $u = \frac{(f_{beat})(c)}{f_s}$

$u = \frac{(990 \text{ Hz})(3 \times 10^8 \text{ m/s})}{3 \times 10^9 \text{ Hz}}$

$u = 99 \text{ m/s}$

6. $\sin \theta = \frac{v}{v_s}$; $\theta = \sin^{-1}\left(\frac{v}{v_s}\right)$

$\theta = \sin^{-1}\left(\frac{0.25 \text{ m/s}}{1 \text{ m/s}}\right)$

$\theta = 14.5°$

8. $f_o = f_s \left(1 - \frac{u}{c}\right)$, $f_o = \frac{c}{\lambda_o}$, $f_s = \frac{c}{\lambda_s}$

$\lambda_s = \lambda_o \left(1 - \frac{u}{c}\right)$

$\lambda_s - \lambda_o = -\lambda_o \left(\frac{u}{c}\right)$ $\lambda_o = \frac{-\lambda_s}{\frac{u}{c} - 1}$

$\lambda_o = \frac{-6000 \text{ Å}}{\frac{1.5 \times 10^6}{3 \times 10^8} - 1} = 6030 \text{ Å}$

3. $I = 10 \log \frac{p^2}{p_o^2}$

$= 10 \log \left[\frac{(0.00002 \text{ N/m}^2)^2}{(0.00002 \text{ N/m}^2)^2} \right]$

$I = 0$ dB

4. $I = 10 \log \frac{p^2}{p_o^2}$

$= 10 \log \left[\frac{(1 \text{ N/m}^2)^2}{(0.00002 \text{ N/m}^2)^2} \right]$

$I = 94.0$ dB

5. Combined sound pressure in $\text{N/m}^2 = 3 \text{ N/m}^2$

$I = 10 \log \frac{p^2}{p_o^2}$

$= 10 \log \left[\frac{(3 \text{ N/m}^2)^2}{(0.00002 \text{ N/m}^2)^2} \right]$

$I = 103.5$ dB

11E1, ALTERNATING VOLTAGE AND CURRENT

2. $V_{rms} = (0.707)\, V_{max}$

$= (0.707)(150\ V)$

$V_{rms} = 106.05\ V$

4. $X_C = \frac{1}{2\pi fC}$

$= \frac{1}{2\pi\ (5000\ Hz)(2 \times 10^{-6}\ F)}$

$X_C = 15.9\ \Omega$

5. $X_C = \frac{1}{2\pi fC}$; $X_C = \frac{V}{I}$, so $I = \frac{V}{X_C} = V(2\pi fC)$

$I = (117\ V)(2\pi)(60\ Hz)(1 \times 10^{-6}\ F)$

$I = 4.4 \times 10^{-2}\ A$

6. $X_L = 2\pi fL$; $X_L = \frac{V}{I}$, so $I = \frac{V}{X_L}$

$X_L = (2\pi)(60\ Hz)(1\ H) = 377\ \Omega$

$I = \frac{117\ V}{377\ \Omega} = 0.31\ A$

11E2, PHASE RELATIONSHIPS IN a.c. CIRCUITS

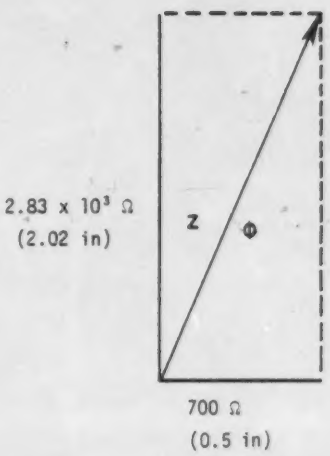
3. $X_L = 2\pi fL$

$X_L = 2\pi\ (1500\ Hz)(300 \times 10^{-3}\ H) = 2.83 \times 10^3\ \Omega$

$Z = \sqrt{(700\ \Omega)^2 + (2.83 \times 10^3\ \Omega)^2} = 2.92 \times 10^3\ \Omega$

$\tan \phi = \frac{X_L}{R} = \frac{2.83 \times 10^3\ \Omega}{700\ \Omega} = 4.04$

$\phi = 76°$



4. $\phi = \tan^{-1}\frac{X_L}{R}$, $X_L = 2\pi fL$, $Z = \sqrt{R^2 + X_L^2}$, power factor $= \frac{R}{Z}$,

apparent power $= V_{rms}I_{rms}$, true power $= V_{rms}I_{rms}\cos\phi$, $I_{rms} = \frac{V_{rms}}{Z}$

$$\phi = \tan^{-1}\left[\frac{2\pi\ (60\ \text{Hz})(50 \times 10^{-3}\ \text{H})}{80\ \Omega}\right] = 13.3°$$

$$z = \sqrt{(80\ \Omega)^2 + [2\pi\ (60\ \text{Hz})(50 \times 10^{-3}\ \text{H})]^2} = 82.2\ \Omega$$

$$\text{power factor} = \frac{80\ \Omega}{82.2\ \Omega} = 0.973$$

$$P_A = (117\ \text{V})\left(\frac{117\ \text{V}}{82.2\ \Omega}\right) = 166.5\ \text{W}$$

$$P_T = (117\ \text{V})\left(\frac{117\ \text{V}}{82.2\ \Omega}\right)(\cos 13.3°) = 162\ \text{W}$$

5. at resonance $2\pi fL = \frac{1}{2\pi fC}$, so $C = \frac{1}{(2\pi f)^2 L}$

$$C = \frac{1}{[2\pi\ (60\ \text{Hz})]^2(50 \times 10^{-3}\ \text{H})}$$

$$C = 140\ \mu\text{F}$$

11E3, OSCILLOSCOPE

7. $f = \frac{1}{T}$

$$T = (0.2 \times 10^{-3}\ \text{s/cm})(7.5\ \text{cm}) = 1.5 \times 10^{-3}\ \text{s}$$

$$f = \frac{1}{1.5 \times 10^{-3}} = 666.7\ \text{Hz}$$

8. $V = (0.2\ \text{V/cm})(6.7\ \text{cm})$

$$V = 1.34\ \text{V}$$

11E4, RECTIFIERS

No calculations required.

11E5, ELECTRONIC FILTERING IN d.c. POWER SUPPLIES

6. (a) $V_{dc} = 1.4\ V_{rms} - \frac{I_L}{2\ fc}$; $I_L \approx \frac{1.4\ V_{rms}}{R_L}$, so

$$V_{dc} = 1.4\ V_{rms} - \frac{1.4\ V_{rms}}{2\ fc\ R_L}$$

$$V_{dc} = 1.4\ (120\ V) - \frac{1.4\ (120\ V)}{2\ (60\ Hz)(50 \times 10^{-6}\ f)(2 \times 10^{3}\ \Omega)} = 154\ V$$

$$r = \frac{1}{210\ C\ R_L} = \frac{1}{210\ (50 \times 10^{-6})(2 \times 10^{3})} = 0.0476$$

(b) $V_{dc} = 1.4\ V_{rms} - I_L \left(\frac{1}{210\ C_1} + R\right)$, (See Table 1)

$$I_L = \frac{1.4\ V_{rms}}{R + R_L} = \frac{1.4\ (800\ V)}{(10 \times 10^{3}\ \Omega + 43 \times 10^{3}\ \Omega)} = 0.0211\ amps$$

$$V_{dc} = 1.4\ (800\ V) - 0.0211\ V/\Omega \left(\frac{1}{240\ (2 \times 10^{-6}\ f)} + 10 \times 10^{3}\ \Omega\right)$$

$$V_{dc} = 865\ V$$

$$r = \frac{2.5 \times 10^{-6}}{C_1 C_2 R\ R_L} = \frac{2.5 \times 10^{-6}}{(2 \times 10^{-6}\ f)(2 \times 10^{-6}\ f)(10000\ \Omega)(43000\ \Omega)}$$

$$r = 0.00145$$

11E6, ELECTRONIC FILTERING FOR FREQUENCY SELECTION

2. (a) $f_c = \frac{1}{2\pi RC}$

$$f_c = \frac{1}{2\pi\ (5000\ \Omega)(0.16 \times 10^{-6}\ f)} = 198.9\ Hz$$

(b) $f_c = \frac{R}{2\pi L}$; $L = \frac{R}{2\pi f_c}$

$$L = \frac{5000\ \Omega}{2\pi\ (198.9\ Hz)} = 4\ H$$

3. (a) $$\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{1 + (2\pi fRC)^{-2}}}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{1 + [2\pi\ (1 \times 10^{6}\ Hz)(5000\ \Omega)(320 \times 10^{-12}\ f)]^{-2}}}$$

$$\frac{V_{out}}{V_{in}} = 9.95 \times 10^{-1}$$

(b) $$\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{1 + \left(\frac{2\pi fL}{R}\right)^{2}}}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{1 + \left[\frac{2\pi\ (1 \times 10^{6}\ Hz)(8 \times 10^{-3}\ H)}{500\ \Omega}\right]^{2}}} = 1.00$$

4. (a) $$f_r = \frac{1}{2\pi\ \sqrt{LC}}$$

$$f_r = \frac{1}{2\pi\ \sqrt{(250 \times 10^{-6}\ H)(0.1 \times 10^{-6}\ f)}} = 3.18 \times 10^{4}\ Hz$$

(b) $$Q = \sqrt{\frac{L}{R^2C}}$$

$$Q = \sqrt{\frac{250 \times 10^{-6}\ H}{(1\ \Omega)^2(0.1 \times 10^{-6}\ f)}} = 50$$

11E7, MODULATIONS OF ELECTRIC WAVES

6. USB = f(c) + f(i) = 200 kHz + 20 kHz = 220 kHz

LSB = f(c) - f(i) = 200 kHz - 20 kHz = 180 kHz

3. $T = T_{amb} + (T_0 - T_{amb})\, e^{-kt}$

$T = (500\ C^\circ)\, e^{-kt}$

(a) $400°C = 500\ C^\circ\, e^{-k(5\ min)}$

$\ln\left(\frac{4}{5}\right) = -k(5\ min)$

$k = 0.0446/min$

(b) $\tau = 1/k$

$\tau = \frac{1}{0.0446/min} = 22.4\ min$

(c) $T = (500\ C^\circ)\, e^{-(1/\tau)(2\ \tau)}$

$T = 67.7°C$

(d) $T = (500\ C^\circ)\, e^{-(1/\tau)(5\ \tau)}$

$T = 3.37°C$

4. (a) $T_{\frac{1}{2}} = \frac{0.693}{\lambda}$; so $\lambda = \frac{0.693}{T_{\frac{1}{2}}}$

$\lambda = \frac{0.693}{4.50 \times 10^9\ yr} = 1.54 \times 10^{-10}/yr$

(b) $N = N_0 e^{-\lambda t}$; so $\frac{N}{N_0} = e^{-\lambda t}$ = fraction remaining at time t.

$\frac{N}{N_0} = e^{-[(1.54 \times 10^{-10}/yr)(9.0 \times 10^9\ yr)]} = 0.25$; 1/4 of the atoms remain.

(c) $A = \lambda N$; so $N = \frac{A}{\lambda}$

$N = \frac{3.70 \times 10^{10}\ d/s}{(1.54 \times 10^{-10}/yr^{-1})(\frac{1\ yr}{365\ days})(\frac{1\ day}{24\ hr})(\frac{1\ hr}{3600\ s})} = 7.58 \times 10^{27}$ atoms

5. (a) $\tau = RC$

$\tau = (1.0 \times 10^6)(0.1 \times 10^{-6})\ s = 0.1\ s$

(b) $I = \frac{V_s}{R} e^{-t/RC}$

$I = \left(\frac{6\ V}{1.0 \times 10^6\ \Omega}\right) e^{0/RC} = \frac{6\ V}{1.0 \times 10^6\ \Omega} = 6 \times 10^{-6}\ A$

(c) $I = \left(\frac{V_s}{R}\right) e^{-2RC/RC}$

$I = \left(\frac{6\ V}{1.0 \times 10^6\ \Omega}\right)(e^{-2}) = 8.12 \times 10^{-7}\ A$

(d) $V_c = V_s\ (1 - e^{-t/\tau})$

$V_c = 6\ V\ (1 - e^{-3\tau/\tau}) = 5.7\ V$

(e) $V_c = V_s\ (1 - e^{-t/\tau})$

$V_c = 6\ V\ (1 - e^{-5\tau/\tau}) = 5.96\ V$

12M1, SHOCK ISOLATION BY ABSORBERS

No calculations required.

12F1, RATE OF EMPTYING TANKS

2. $\tau_c = RC\ ;\ C = \frac{A}{\rho_w}$, so $\tau_c = \frac{RA}{\rho_w}$

$\tau_c = 3 \times 10^7\ pa/(m^3/s)\ \left[\frac{300\ m^2}{(1 \times 10^3\ kg/m^3)(9.8\ m/s^2)}\right] = 9.18 \times 10^5\ s$

3. $h = h_o\ e^{-t/\tau_c}$

$= (8.0\ m)\ e^{-26\ min/20\ min}$

$h = 2.18\ m$

4. $t = 5\ \tau_c$

$= 5\ (3\ s)$

$t = 15\ s$

5. (a) $\tau_c = \frac{t}{\ell n\ (\frac{h_o}{h})}$

$\tau_c = \frac{3\ min}{\ell n\ (\frac{15\ m}{11\ m})} = 9.67\ min = 580.2\ s$

(b) $C = \frac{A}{\rho_w} = \frac{75\ m^2}{(1 \times 10^3\ kg/m^3)(9.8\ m/s^2)} = 7.65 \times 10^{-3}\ m^3/pa$

(c) $R = \frac{\tau_c}{C} = \frac{580.2\ s}{7.65 \times 10^{-3}\ m^3/pa} = 7.58 \times 10^4\ pa/(m^3/s)$

(d) $t = 5\ \tau_c = 5(580.2\ s) = 2901\ s$

(e) $\frac{\Delta v}{\Delta t} = \frac{1}{\tau_c} Ah$ (See Example C part [e])

$$\frac{\Delta v}{\Delta t} = \frac{1}{580.2\ s}(75\ m^2)\ 4\ m = 0.517\ m^3/s$$

12E1, RC CIRCUITS

2. $V_c = V_T\ (1 - e^{-t/RC})$

$$= 12\ V\left[1 - e^{(-5 \times 10^{-3}\ s)/(10 \times 10^3\ \Omega)(0.44 \times 10^{-6}\ f)}\right]$$

$$V_c = 8.15\ V$$

3. $V_c = V_T\ e^{-t/RC}$

$$= (12\ V)\left[e^{(-1 \times 10^{-3}\ s)/(2 \times 10^3\ \Omega)(0.44 \times 10^{-6}\ f)}\right]$$

$$V_c = 3.85\ V$$

4. $t = -\tau \ell n\ (1 - \frac{V_c}{V_T})$

$$= -(10 \times 10^3\ \Omega)(0.44 \times 10^{-6}\ f)\ \ell n\ (1 - \frac{10\ V}{12\ V})$$

$$t = 7.88 \times 10^{-3}\ s$$

5. $t = -\tau \ell n\ (\frac{V_c}{V_T})$

$$= -(2 \times 10^3\ \Omega)(0.44 \times 10^{-6}\ f)\ \ell n\ (\frac{5\ V}{12\ V})$$

$$t = 7.7 \times 10^{-4}\ s$$

6. $t_1 = 0.693(R_A + R_B)(C)$, $t_2 = 0.693\ (R_B)(C)$, so $R_B = \frac{t_2}{(0.693)(C)}$

$$R_B = \frac{0.25 \times 10^{-3}\ s}{(0.693)(0.01 \times 10^{-6}\ f)} = 3.61 \times 10^4\ \Omega$$

$$R_A + R_B = \frac{t_1}{(0.693)(C)} = \frac{0.75 \times 10^{-3}\ s}{(0.693)(0.01 \times 10^{-6}\ f)} = 1.08 \times 10^5\ \Omega$$

$$R_A = 1.08 \times 10^5\ \Omega - R_B = 1.08 \times 10^5\ \Omega - 3.61 \times 10^4\ \Omega = 7.19 \times 10^4\ \Omega$$

12E2, RL CIRCUITS

2. $\tau_L = L/R$

$$\tau_L = \frac{200 \times 10^{-6}\ H}{1\ \Omega} = 200 \times 10^{-6}\ s$$

4. $$\tau_L = L/R = \frac{60 \times 10^{-3} H}{30\ \Omega} = 2 \times 10^{-3}\ s$$

(a) $$I_E = \frac{V_o}{R} e^{-t/\tau_L} = \left(\frac{6\ V}{30\ \Omega}\right) e^{(-0.4\ ms/2\ ms)} = 0.164\ A$$

$$V_{Rt} = V_o e^{-t/\tau_L} = (6\ V)\, e^{(-0.4\ ms/2\ ms)} = 4.91\ V$$

$$V_{Lt} = -V_{Rt} = -4.91\ V$$

$$W_t = \tfrac{1}{2} LI^2 = \tfrac{1}{2} (60 \times 10^{-3}\ H)(0.164\ A)^2 = 8.1 \times 10^{-4}\ J$$

(b) $$I_t = \frac{V_o}{R}(1 - e^{-t/\tau_L}) = \frac{6\ V}{30\ \Omega}\left[1 - e^{(0.4\ ms/2\ ms)}\right] = 0.0363\ A$$

$$V_{Rt} = I_t(R) = (0.0363\ A)(30\ \Omega) = 1.089\ V$$

$$V_{Lt} = V_o e^{-t/\tau_L} = (6\ V)\, e^{(-0.4\ ms/2\ ms)} = 4.91\ V$$

$$W_t = \tfrac{1}{2} LI^2 = \tfrac{1}{2} (60 \times 10^{-3}\ H)(0.0363\ A)^2 = 3.95 \times 10^{-5}\ J$$

12E3, RLC CIRCUITS

4. (a) $\Delta t_{1/3} = \tau C$, so $C = \frac{\Delta t_{1/3}}{R}$

$$C = \frac{0.5 \times 10^{-3}\ s}{0.5\ \Omega} = 1 \times 10^{-3}\ f$$

(b) $$L = \frac{R^2 C}{4}$$

$$L = \frac{(0.5\ \Omega)^2 (1 \times 10^{-3}\ f)}{4} = 6.25 \times 10^{-5}\ H$$

(c) $E = \tfrac{1}{2} CV^2$, so $V = \sqrt{\frac{2E}{C}}$

$$V = \sqrt{\frac{2\ (600\ J)}{(1 \times 10^{-3}\ f)}} = 1.1 \times 10^{3}\ V$$

12T1, RESPONSE TIME OF THERMOCOUPLES

2. $t_c = \frac{mc}{(k_h)\,A}$

$t_c = \frac{(0.006\ g)(0.15\ cal/g\cdot C^\circ)}{(0.03\ cal/cm^2\cdot s\cdot C^\circ)(0.01\ cm^2)}$

$t_c = 3\ s$

3. $T = T_f - (T_f - T_i)\, e^{-t/t_c}$

$T = (-196°C) - (-196°C - 20°C)\, e^{-t/3s}$

$T = -196°C + (216)\, e^{-t/3s}$

when $t = 0$, $T = 20°C$

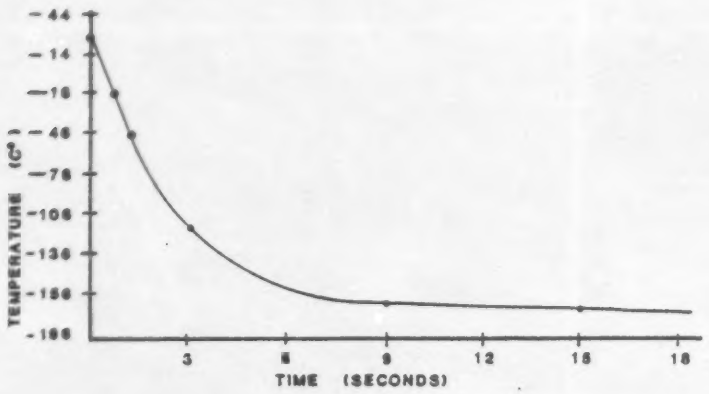
when $t = 0.5$ s, $T = -13.2°C$

when $t = 1$ s, $T = -41.2°C$

when $t = 3$ s, $T = -116.5°C$

when $t = 3\ t_c$, $T = -185.2°C$

when $t = 5\ t_c$, $T = -194.5°C$



12T2, TIME CONSTANTS OF HEATING AND COOLING

1. $T_{eq} = 5\ \tau$; $\frac{\Delta T}{\Delta t} = \frac{T_B - T}{\tau}$

(a) Thermometer B reaches equilibrium first.

(b) Thermometer B has the larger initial rate of temperature change.

2. $t_{eq} = 5\,\tau$; $\tau = \frac{t_{eq}}{5}$

$\tau = \frac{4 \text{ min}}{5}$

$\tau = 0.8 \text{ mm} = 48 \text{ s}$

3. $T = T_o + (T_g - T_o)\,[1 - e^{-t/\tau}]$

$= 80°F + (300°F - 80°F)[1 - e^{-0.5 \text{ s}/0.7 \text{ s}}]$

$T = 192.3°F$

4. $T = T_{AMB} + [T_o - T_{AMB}]\, e^{-t/\tau}$

$100°F = 70°F + [150°F - 70°F]\, e^{-15 \text{ min}/\tau}$

(a) $0.375 = e^{-15 \text{ min}/\tau}$; $\tau = \frac{-15 \text{ min}}{\text{Ln } (0.375)} = 15.29 \text{ min}$

(b) $T = 70°F + [150°F - 70°F]\, (e^{-20 \text{ min}/15.29 \text{ min}})$

$T = 91.6°F$

5. $t_{eq} = 5\,\tau$, $\tau = \frac{t_{eq}}{5}$; $T = T_{AMB} + [T_o - T_{AMB}]\, e^{-t/\tau}$

$\tau = \frac{35 \text{ s}}{5} = 7 \text{ s}$

$T = 20°C + (500°C - 20°C)\, e^{-14 \text{ s}/7 \text{ s}}$

$T = 84.96°C$

6. $\tau = \frac{T - T_{AMB}}{(\frac{\Delta T}{\Delta t})}$; $\frac{\Delta T}{\Delta t} = \frac{T - T_{AMB}}{\tau}$

$\tau = \frac{20 \text{ C°}}{0.25 \text{ C°/s}} = 80 \text{ s}$

$\frac{\Delta T}{\Delta t} = \frac{60 \text{ C°}}{80 \text{ s}} = 0.75 \text{ C°/s}$

3. (a) $c = \lambda f$; $f = \frac{c}{\lambda}$

$$f = \frac{3 \times 10^8 \text{ m/s}}{0.03 \text{ m}} = 1 \times 10^{10} \text{ Hz}$$

(b) $E = hf$

$$E = (6.6 \times 10^{-34} \text{ J·s})(10^{10} \text{ Hz}) = 6.6 \times 10^{-24} \text{ J}$$

4. $f = \frac{c}{\lambda}$

$$f = \frac{3 \times 10^8 \text{ m/s}}{555 \times 10^{-9} \text{ m}} = 5.4 \times 10^{14} \text{ Hz}$$

Light of this frequency is yellow-green.

$$E = (6.6 \times 10^{-34} \text{ J·s})(5.4 \times 10^{14} \text{ Hz}) = 3.56 \times 10^{-19} \text{ J}$$

5. $P_1 = \frac{P_0}{d_1^2}$; $6\,P_1 = \frac{P_0}{d_2^2}$, so $P_1 = \frac{P_0}{6d_2^2}$

$$\frac{P_0}{d_1^2} = \frac{P_0}{6d_2^2} \; ; \quad \frac{P_0}{(8 \text{ ft})^2} = \frac{P_0}{6d_2^2}$$

$$6\,(d_2)^2 = 64 \text{ ft}^2$$

$$d_2 = 3.27 \text{ ft}^2$$

6. $\lambda = \frac{c}{f}$, $E = hf$

EM Radiation	Mid-frequency (from Fig. 2)	Wavelength (Calculated)	Energy (Joules) (Calculated)
a.c. power	75 Hz	4×10^6 m	4.95×10^{-32} J
Radio	9×10^6 Hz	33.3 m	5.9×10^{-27} J
AM	9×10^5 Hz	333 m	5.9×10^{-28} J
TV, FM	10^8 Hz	3 m	6.6×10^{-26} J
Radar	2×10^{10} Hz	1.5×10^{-2} m	1.3×10^{-23} J
Microwave	9.5×10^{10} Hz	3.16×10^{-3} m	6.3×10^{-23} J
Infrared	9.5×10^{12} Hz	3.16×10^{-5} m	6.3×10^{-21} J
Visible	6×10^{14} Hz	5×10^{-7} m	4×10^{-19} J
Ultraviolet	8×10^{16} Hz	3.75×10^{-9} m	5.3×10^{-17} J
X-rays	10^{19} Hz	3×10^{-11} m	6.6×10^{-15} J
Gamma rays	9×10^{20} Hz	3.3×10^{-13} m	5.9×10^{-13} J

8. $E = hf$, so $f = \frac{E}{h}$, $\lambda = \frac{c}{f}$, $n = \frac{c}{v}$, so $v = \frac{c}{n}$

$$f = \frac{(3 \times 10^4 \text{ eV})(\frac{1.6 \times 10^{-19} \text{ J}}{1 \text{ eV}})}{6.6 \times 10^{-34} \text{ J s}} = 7.27 \times 10^{20} \text{ Hz}$$

$$\lambda = \frac{3 \times 10^8 \text{ m/s}}{7.27 \times 10^{20} \text{ Hz}} = 4.13 \times 10^{-13} \text{ m}$$

$$v = \frac{3 \times 10^8 \text{ m/s}}{1.5} = 2 \times 10^8 \text{ m/s}$$

13L1, INVERSE-SQUARE LAW — SPREADING OF LIGHT

3. $E = \frac{I}{R^2}$

$$E = \frac{5 \text{ W/sr}}{(25 \text{ m})^2} = 0.008 \text{ W/m}^2$$

4. $E = \frac{I}{R^2}$; $R = \sqrt{\frac{I}{E}}$

$$R = \sqrt{\frac{150 \text{ W/sr}}{0.25 \times 10^{-3} \text{ W/(.01 m)}^2}} = 7.75 \text{ m}$$

5. $E = I/R^2$; $I = ER^2$

$$I = \frac{0.03 \times 10^{-3} \text{ W}}{(.01 \text{ m})^2} (15 \text{ m})^2 = 67.5 \text{ W/sr}$$

$$E = \frac{I}{R^2} = \frac{67.5 \text{ W/sr}}{(20 \text{ m})^2} = 0.169 \text{ W/m}^2$$

13L2, THE OPTICAL SPECTRUM

3. $E = hf$, $f = \frac{c}{\lambda}$, $\lambda = \frac{c}{f}$, $f = \frac{E}{h}$

Color	Energy of Photon (J)	Frequency (Hz)	Wavelength (nm)
Red	3.05×10^{-19}	4.62×10^{14}	650
Green	3.81×10^{-19}	5.78×10^{14}	519
Blue	4.73×10^{-19}	7.17×10^{14}	419

13L3, LIGHT SOURCES

No calculations required.

13L4, LASERS

No calculations required.

13L5, STROBOSCOPES – LIGHT PULSES

No calculations required.

13L6, OPTICAL FILTERS – ABSORPTION OF LIGHT

3. $T = e^{-kx}$

$= e^{-(6.3\ cm^{-1})(0.5\ cm)}$

$T = 0.043$

4. $k = \frac{1}{x} \ln \left(\frac{1}{T}\right)$

$= \frac{1}{1.2\ cm} \ln \left(\frac{1}{0.82}\right)$

$k = 0.165\ cm^{-1}$

6. $T = 10^{-OD}$

$= 10^{-2}$

$T = 0.01$

13L7, SPECULAR AND DIFFUSE REFLECTIONS OF LIGHT

No calculations required.

13L8, IMAGE FORMATION WITH MIRRORS

4. $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$

$\frac{1}{10\ cm} = \frac{1}{15\ cm} + \frac{1}{q}$

q = 30 cm in front of mirror

5. $h_i = h_0 \times (\frac{q}{p})$

$h_i = 2\ cm\ (\frac{30\ cm}{15\ cm}) = 4\ cm$

6. $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$

$\frac{1}{f} = \frac{1}{10} - \frac{1}{2}$

f = -2.5 cm, mirror is convex

7. $h_i = h_o\ (\frac{q}{p})$

$0.6\ cm = h_o(\frac{2\ cm}{10\ cm})$

$h_o = 3\ cm$

13L9, PRISMS – REFRACTION AND DISPERSION OF LIGHT

2. $n = \frac{c}{v}$, so $v = \frac{c}{n}$

$v = \frac{3 \times 10^8\ m/s}{1.45}$

$v = 2.07 \times 10^8\ m/s$

3. $n_a \sin A = n_c \sin C$, so $\sin A = \frac{n_c \sin C}{n_a}$

$\sin A = \frac{(1.33) \sin 32°}{(1.0)} = 0.705$

$\angle A = 44.8°$

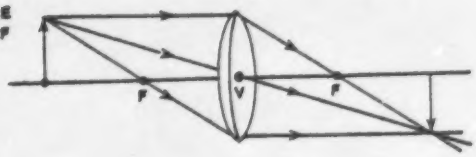
4. $n_a \sin A = n_c \sin C$, so $\sin C = \frac{n_a \sin A}{n_c}$

$\sin C = \frac{(1.33) \sin 55°}{1.64} = 0.664$

$\angle C = 41.6°$

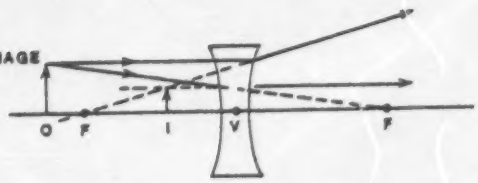
13L10, LASERS – FOCUSING AND SPREADING OF LIGHT

1. (a) REAL IMAGE NEAR q = 2F



(b) VIRTUAL IMAGE NEAR q = -F

(c) VIRTUAL IMAGE BETWEEN F AND V



3. $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$

$\frac{1}{-2.0\ cm} = \frac{1}{300\ cm} + \frac{1}{q}$

$q = -1.99\ cm$

$h_i = h_o\ (\frac{q}{p})$

$h_i = 6\ ft\ (\frac{1.99\ cm}{300\ cm}) = .04\ ft$

4. $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$

$\frac{1}{f} = \frac{1}{8.5\ cm} + \frac{1}{230\ cm}$

$f = 8.2\ cm$

5. $P(D) = \frac{1}{f(m)}$

$10 = \frac{1}{f(m)}$

$f = 0.1\ m$

6. $P = \frac{1}{f}$

$= \frac{1}{.025\ m}$

$P = 40\ D$

13L11, INTERFERENCE – TESTING FLAT SURFACES

3. $A = \frac{\lambda}{2x}$

$A = \frac{633 \times 10^{-9}\ m}{2\ (2.5 \times 10^{-4})\ m}$

$A = 1.27 \times 10^{-3}$ rad

13L12, DIFFRACTION GRATING, MEASURING THE WAVELENGTH OF LIGHT

4. $d \sin A = m \lambda$; so $\sin A = \frac{m\lambda}{d}$

(a) $\sin A = \frac{(1)(400 \times 10^{-9}\ m)}{2 \times 10^{-6}\ m} = 0.2$

$A = 11.54°$

(b) $\sin A = \frac{(1)(650 \times 10^{-9}\ m)}{2 \times 10^{-6}\ m} = 0.325$

$A = 18.97°$

(c) $\sin A = \frac{(2)(550 \times 10^{-9}\ m)}{2 \times 10^{-6}\ m} = 0.55$

$A = 33.37°$

5. $d \sin A = m \lambda$; so $d = \frac{m \lambda}{\sin A}$

$d = \frac{(4)(633 \times 10^{-9}\ m)}{\sin 42°}$

$d = 3.78 \times 10^{-6}\ m$

6. $d \sin A = m \lambda$; so $\lambda = \frac{d \sin A}{m}$

$\lambda = \frac{(3.78 \times 10^{-6}\ m)(\sin 42°)}{3}$

$\lambda = 8.43 \times 10^{-7}\ m$ (843 nm)

13L13, POLARIZATION – GLARE REDUCTION

3. $T = \cos^2 A$, $P_2 = T(P_1)$

(a) $T = \cos^2 (45°) = 0.5$

$P_2 = (0.5)\ 10\ mW = 5\ mW$

(b) $T = \cos^2 (90°) = 0$

$P_3 = (0)\ 5\ mW = 0\ mW$, no light is transmitted

13L14, HOLOGRAPHY – THREE DIMENSIONAL PHOTOGRAPHY

No calculations required.

13L15, SPECTROSCOPY – LIGHT ANALYSIS

No calculations required.

13L16, INFRARED RADIATION THERMOMETERS

2. (a) $E = \varepsilon\sigma T^4$

$= 0.75\ (5.67 \times 10^{-8}\ W/m^2K^4)(550\ K)^4$

$E = 3.89 \times 10^3\ W/m^2$

(b) $T = \dfrac{T_A}{\sqrt[4]{\varepsilon}}$; $T_A = (T)\sqrt[4]{\varepsilon}$

$T_A = (550\ K)(\sqrt[4]{0.75}) = 511.8\ K$

13L17, ILLUMINATION

2. (a) $I = \dfrac{F}{\omega}$; $F = I\omega$; $\omega = 2\pi$ sr

$F = (160\ cd)(2\pi\ sr)$

$F = 1005.3\ lm$

(b) $E = \frac{F}{A}$; $A = 2\pi R^2$

$$E = \frac{1005.3 \text{ lm}}{2\pi (0.5)^2 m^2}$$

$$E = 640 \text{ lm/m}^2 = 640 \text{ lx}$$

3. $L = \frac{F_{out}}{P_{in}}$

(a) $L = \frac{1800 \text{ lm}}{100 \text{ W}} = 18 \text{ lm/W}$ (more efficient)

(b) $L = \frac{1200 \text{ lm}}{75 \text{ W}} = 16 \text{ lm/W}$

6. $E = \frac{F}{A}$ = let N be the number of bulbs

$E_T = \frac{NF}{A} = 10$ fc, $N = \frac{10 \text{ fc } (A)}{F}$

$$N = \frac{(10 \text{ lm/ft}^2)(15 \text{ m} \times 12 \text{ m})(\frac{3.28 \text{ ft}}{1 \text{ m}})^2}{3000 \text{ lm}} = 6.45, \text{ so 7 bulbs are required}$$

13L18, SINGLE LENS REFLEX CAMERA

2. $d = f = \sqrt{w^2 + h^2}$

$$f = \sqrt{(2.25 \text{ in})^2 + (2.25 \text{ in})^2}$$

$f = 3.18$ in

3. The f stop number index should be placed on the next lowest setting.

13N1, GEIGER COUNTERS

No calculations required.

13N2, PENETRATING POWER OF ALPHA AND BETA RADIATION

No calculations required.

13N3, RADIOACTIVITY

3. $N(t) = N_o e^{-\ell n\,(\frac{2t}{T_{\frac{1}{2}}})}$

$$\ell n\left(\frac{N(t)}{N_o}\right) = -\ell n\ 2\ (t/T_{\frac{1}{2}})$$

$$T_{\frac{1}{2}} = \frac{-t\ \ell n\ 2}{\ell n\ (\frac{N(t)}{N_o})} = \frac{(-3\ \text{days})(0.693)}{\ell n\ \frac{0.57 \times 10^{18}\ \text{atoms}}{1.25 \times 10^{19}\ \text{atoms}}} = 0.673\ \text{day}$$

4. $Q(t) = \frac{N(t)}{T_{\frac{1}{2}}}\ \ell n\ 2\ ;\ N(t) = \frac{T_{\frac{1}{2}}\ Q(t)}{\ell n\ 2},\quad N_o = \frac{T_{\frac{1}{2}}\ Q_o}{\ell n\ 2}$

$$\frac{N(t)}{N_o} = \frac{T_{\frac{1}{2}}\ Q(t)/\ell n\ 2}{T_{\frac{1}{2}}\ Q_o/\ell n\ 2} = \frac{Q(t)}{Q_o} = \frac{2684\ \text{decays/min}}{(15.3\ \text{decays/min}\cdot\text{g})(225\ \text{g})}$$

$$\frac{N(t)}{N_o} = 0.78 = e^{\ (-\ell n\ 2)(t/T_{\frac{1}{2}})}$$

$$\ell n\ (0.78) = (-\ell n\ 2)(t/T_{\frac{1}{2}})$$

$$t = -\frac{\ell n\ (0.78)(T_{\frac{1}{2}})}{\ell n\ 2} = \frac{\ell n\ (0.78)(5568\ \text{yr})}{\ell n\ 2} = 1996\ \text{yr}$$

13N4, ABSORPTION OF GAMMA RADIATION

5. $I_x = I_o\ e^{-\mu_m \rho x}\quad ;\ \frac{I_x}{I_o} = e^{-\mu_m \rho x}$

(a) $\frac{I_x}{I_o} = e^{-(0.2\ \text{cm}^2/\text{gm})(1\ \text{gm/cm}^3)(1\ \text{cm})} = 0.819$

(b) $\frac{I_x}{I_o} = e^{-(0.2\ \text{cm}^2/\text{gm})(1\ \text{gm/cm}^3)(10\ \text{cm})} = 0.135$